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THESIS – THÈSE

Title of Thesis – Titre de la thèse

ISOKINETIC TORQUE PATTERNS FOLLOWING ANTERIOR CRUCIATE LIGAMENT INJURY

Degree for which thesis was presented Grade pour lequel cette thèse fut présentée	Year this degree conferred Année d'obtention de ce grade
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ISOKINETIC TORQUE PATTERNS FOLLOWING ANTERIOR CRUCIATE LIGAMENT INJURY

by

JANE PROCTOR

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF SCIENCE

DEPARTMENT OF PHYSICAL THERAPY

EDMONTON, ALBERTA

SPRING 1985

THE UNIVERSITY OF ALBERTA

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submitted by JANE PROCTOR
in partial fulfilment of the requirements for the degree of Master of Science in Physical Therapy.

Supervisor

DATE

To Mom and Dad

and

Maryann and Lorne

ABSTRACT

The purpose of the study was to examine the torque patterns during maximum voluntary isokinetic contractions of the quadriceps and hamstring muscles in subjects having a) a third degree sprain (rupture) of the anterior cruciate ligament of the knee (Group I), and b) a third degree sprain of the anterior cruciate ligament, plus a partial menisectomy to remove a fragment of the torn meniscus (Group II). An isokinetic dynamometer with a dual channel recorder was used to correlate torque and range of movement in both the injured and uninjured knees of individual subjects. The test routine was repeated at two angular velocities: a) thirty degrees per second, and b) one hundred and eighty degrees per second. Group I consisted of seven subjects, ranging in age from twenty-four to forty-one years, mean time since injury 15.4 months, and Group II had ten subjects, aged twenty-one to fifty-one years, mean time since injury 31.5 months. A third group (III) of fifteen subjects, ranging in age from twenty-two to forty-four years, with normal, uninjured knees, was also tested as a control group.

Torque measurements at fifteen degree increments throughout knee flexion and extension were taken from the

pen recordings. Difference scores, the values of stronger or uninjured legs minus the values of the weaker or injured legs were compared over three groups, two types of motion, two angular velocities, and four joint angles using a four-way analysis of variance. The pattern of torque for the injured legs was the same as that of the uninjured legs, in both Groups I and II. These patterns corresponded to the patterns of the weak and strong legs of the control group (III).

Difference scores for angle of occurrence of peak torque, values of stronger or uninjured legs minus the values of the weaker or injured legs, were compared over two types of motion and two angular velocities, and three groups using a three-way analysis of variance. Group II was significantly different than Groups I and III. This significant difference indicated that the angle of occurrence of peak torque, averaged over both angular velocities and over type of motion, differed significantly with injury to the anterior cruciate and the meniscus. However, Tukey tests to compare raw scores of angle of occurrence of peak torque showed no significant difference between injured and uninjured leg values within Group II, indicating that no one particular combination of movement and angular velocity was uniquely responsible for overall significance.

The results suggest two possible causes for the significant difference: a) time since injury, or b) the partially absent meniscus. Increased time since injury may allow progressive stretching of secondary soft tissue restraints, as well as allowing a greater change in the physical activity, and thus the muscle activity, of the subjects. Partial removal of a torn meniscus may increase the anterior movement of the tibia on the femur when the primary restraint, the anterior cruciate ligament is completely torn. The result is an alteration in the angle of occurrence of peak torque when averaged over two motions, flexion and extension, and two selected angular velocities, and expressed as the difference between the injured and the uninjured legs. Since Group I subjects with isolated anterior cruciate ligament tears did not follow this trend, this study suggests that the increased time since injury, and/or a partially absent meniscus, may be the primary factor responsible for the alteration in the difference scores.

The present study has provided initial information suggesting a trend in alteration of angle of occurrence of peak torque in the quadriceps and hamstring muscles following an anterior cruciate ligament rupture and partial removal of the meniscus.

ACKNOWLEDGEMENTS

I wish to thank my supervisor, Dr. D. Magee, and my committee members, Dr. J. Kramer, Dr. R. Jackson, Dr. G. Arnett, and Dr. J. Vargo for their advice and guidance. I am grateful to Dr. R. Jackson, his staff, and the co-operative patients who made this study possible.

Thanks also to Dr. J. Rathbun at Scarborough General Hospital, and to the Rehabilitation Departments at Toronto Western Hospital and Edmonton Workers' Compensation Board for their assistance and encouragement.

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CHAPTER 1

THE PROBLEM

1. Statement of the Problem

Physical therapists recognize the importance of the knee muscles in rehabilitation after anterior cruciate ligament injury. However, there is a lack of published information concerning actual response of knee flexor and extensor muscles to this injury.

Therapists base their treatment programs for patients with an anterior cruciate deficiency largely on clinical experience and knowledge of the disability.[1] The hamstring muscles can reinforce the action of the anterior cruciate ligament, while the quadriceps muscles can act as antagonists to the hamstrings.[2] Consequently, rehabilitation programs commonly begin with strengthening exercises for the muscles of knee flexion in an attempt to provide the required protection to the kneee with an injured anterior cruciate ligament. Frequently, treatment includes strengthening of the triceps surae muscles with hamstring muscle exercises in the initial stages in an attempt to

further improve the protective capability of the knee flexor muscles.[3,4]

The purpose of this study was to examine the possible change in the torque pattern during maximum voluntary isokinetic contractions of the quadriceps and hamstring muscles, when the anterior cruciate ligament of the knee had been ruptured (third degree sprain), and when the anterior cruciate ligament had been injured and a meniscus partially torn. Knowledge of the torque patterns would be of value in diagnosis and treatment of similar injuries.

2. Objective of the Study

The primary objective of this study was to record and describe the torque pattern throughout knee extension and flexion, during maximal isokinetic contraction at two angular velocities, in normal knees and in knees with ruptured anterior cruciate ligaments, and knees with ruptured anterior cruciate ligaments and partial meniscal tears.

3. Research Hypotheses

i. In response to a third degree sprain of the anterior cruciate ligament, the torque-angle relationships produced during maximum voluntary isokinetic contraction of the hamstring muscles and the quadriceps muscles at specific

angular velocities, will be different than the torque-angle relationships produced by the normal leg.

ii. In response to a third degree sprain of the anterior cruciate ligament and a partial tear of the meniscus, the torque-angle relationships produced during maximum voluntary isokinetic contraction of the hamstring muscles and the quadriceps muscles, at specific angular velocities, will be different than the torque-angle relationships produced by the normal leg.

4. Significance of the Study

Injury to the anterior cruciate ligament has been called "the beginning of the end for the knee."[5] The consequences of insufficiency involve the well documented "anterior cruciate syndrome" with progressive instability of the knee joint.[6] In this syndrome, the inevitable deterioration in knee joint function leads to medial and lateral meniscal tears, articular cartilage erosion, and altered extensor mechanism function. This progression is the result of altered biomechanics with repetitive forward or rotational subluxation of the tibial plateau on the femoral condyle, then reduction as the knee approaches extension or further flexion.

Pictorial representation of dynamic strength capacity of the muscle during movement at a constant velocity as

provided by a Cybex® isokinetic device allows more detailed evaluation of the quadriceps and hamstring muscles response to altered internal joint mechanics.[7] Knowing the typical response of these muscles, in terms of the pattern of torque produced on isokinetic movement in the presence of an anterior cruciate ligament rupture, could provide a more scientifically acceptable baseline of information about which rehabilitation goals could be determined. This information would also be useful in the diagnosis of knees with possible damage to the primary and secondary anterior tibial restraints.

5. Operational Definitions

i. Ligament Injury

The term ligament injury refers to complete tearing (third degree sprain) or rupture of the fibers of both the anteromedial and posterolateral bands of the anterior cruciate ligament. It may include avulsion of bone at either attachment. Because the anterior cruciate ligament is the primary restraint of anterior glide of the tibia on the femur, this injury would cause anterior instability of the knee joint unless the secondary restraints were intact.[8] Secondary restraints to anterior movement are the medial and lateral collateral ligaments, fibrous capsule, and posterior horns of the menisci.

ii. Pivot Shift

Pivot shift is a form of knee instability which occurs when the subject with a torn anterior cruciate ligament suddenly changes direction or stops abruptly during weight bearing. It commonly occurs at about thirty degrees of flexion as the knee approaches full extension (full extension being zero degrees). The iliotibial band passes anterior to the center of rotation of the femoral condyle and thus becomes an extensor or subluxor rather than a flexor or reducer.[9] In addition, while the quadriceps muscle is attempting to extend the knee it has an anterior subluxing effect on the proximal tibia. Ellison[10] reported reflex inhibition of the quadriceps muscle at the moment of subluxation, and with relaxation, the power was lost and the knee flexed. In addition, the iliotibial band passed posterior to the center of rotation and became a flexor again. This subluxation was experienced as a "giving away" and was often described as a "pop" by subjects in the present study.

The pivot shift was reproduced as a test for diagnosis, with the subject in supine. The subject's leg was lifted and the tibia internally rotated by the examiner grasping just above the ankle. The heel of the examiner's other hand was placed over the lateral tibial plateau and fibular head, acting as a fulcrum for a strong valgus force. As the knee

was flexed from a nearly extended position, reduction of the subluxed tibia was felt at approximately thirty degrees.[11] Galway and MacIntosh[12] noted that the entire tibia slid forward subluxing under the femoral condyles, but in this situation, the instability due to anterior cruciate ligament insufficiency dominated in the lateral compartment because the axis of the knee joint was shifted somewhat medially. They felt that as the examiner became more skilled, it was easier to reproduce the subluxation. This learned skill accounted for the inability of some examiners to produce the pivot shift in all cases of anterior cruciate insufficiency, and particularly with an isolated tear.

Correlating clinical evaluation with isolated partial ruptures of the anterior cruciate ligament as confirmed by arthroscopic examination, Jackson[13] found the pivot shift test to be associated only with tearing of the posterolateral band of the anterior cruciate ligament. He found the pivot shift test to be negative with isolated anteromedial band tears.

iii. Anterior Drawer Test

The anterior drawer test was performed with the subject in supine, the hip flexed to forty-five degrees, the knee flexed to ninety degrees, and the tibia in neutral rotation (FIGURE 1). The tester's thumb was placed on each tibial

FIGURE 1: Anterior drawer test

condyle to assess the relative displacement of each condyle. The patient was relaxed. The examiner, with fingers wrapped behind the tibial condyles, attempted to draw the tibia anteriorly. Both tibial condyles coming straight forward as compared to the opposite knee were positive evidence of a torn anterior cruciate ligament.[8,12,14] If medial and lateral knee structures were not damaged in addition to the anterior cruciate ligament, there was no forward displacement by performing the drawer test with the tibia in a position of external rotation or internal rotation.[8,15]

Jackson[13] reported that the anterior drawer test examined the integrity of the anteromedial band of the anterior cruciate ligament. Since the anteromedial band is tense in ninety degrees of knee flexion and the posterolateral band is not, he felt that the anterior drawer test was positive if the anteromedial band was torn.

During clinical drawer tests, the examiner is able to apply only a small force compared to forces acting through activity.[16] This difference explains why a low muscle resistance, especially in the hamstring muscles, in the acutely injured knee, can easily block the clinical drawer test.

iv. Lachmann Test

This test is an anterior drawer test performed with the knee in a position of thirty degrees of flexion or less

FIGURE 2: Lachmann test

(FIGURE 2). The Lachmann test is considered to be the most accurate sign of anterior cruciate rupture.[8,14,17] To perform the test, the examiner grasped the upper tibia with one hand and the lower femur with the other and pulled anteriorly on the tibia. At this angle of flexion, the medial collateral ligament was not taut, and the iliotibial tract contributed minimally to stabilization. The anterior cruciate ligament was the main restraint to movement. The test was positive if the anterior glide of the tibia was in excess to that of the uninjured knee.

Jackson[13] identified the Lachmann test with lack of integrity of the posterolateral band of the anterior cruciate ligament. Since the posterolateral band becomes taut as the knee is brought into extension, he felt the Lachmann test was positive if the posterolateral band was torn.

v. Arthroscopic Examination

This diagnostic technique was performed under anesthetic in aseptic conditions by Dr. R. W. Jackson. The technique involves direct visualization, through a narrow optic tube, of the structures in the knee joint (FIGURE 3). The scope had a light source and a lens system to magnify the images seen, and a camera was modified to fit the arthroscope so that photographs could be taken.

FIGURE 3: Arthroscopic examination of the knee from the anterolateral approach

The entire joint was normally examined as a matter of routine so that no area of injury was overlooked.[18] Examination was done by directing the arthroscope toward the structures of interest from one point of insertion, usually anterior at the joint line, just lateral to the patellar tendon. When the arthroscope was directed toward the intercondylar region, the insertion of anterior cruciate ligament was magnified by its proximity to the lens, and the ligament was seen as it tapered to its origin in the intercondylar notch.

The anterior cruciate ligament was covered with synovium that sometimes masked an incomplete tear, but subsynovial haemorrhagic areas could be seen.[18] If a complete rupture had occurred, the mop-like ends of the torn cruciate ligament could easily be identified and the site of rupture determined.

vi. Partial Tears of the Meniscus

A partial tear of the meniscus was a well-defined lesion of the medial or lateral meniscus in the knee joint. In the current study, this partial tear was one of several types, as described by Jackson and Dandy.[19]

Longitudinal or transverse lacerations were the most common meniscal lesion. This injury may be a bucket handle tear, where the central fragment of the meniscus is

displaced medially, and could lie in the intercondylar notch (FIGURE 4A). Transverse lacerations of the meniscus are more common on the lateral side (FIGURE 4B).[13]

Peripheral separations of the posteromedial corner of the meniscus are characterized by an inward bulging of the inner border of the meniscus (FIGURE 4C). Flaps and tags (FIGURE 4D) are the result of small splits along the inner border of the meniscus, most commonly toward the anterior horn. They often cause of a sensation of instability.[19]

Horizontal cleavage tears (FIGURE 4E) are the result of degenerative changes which allowed horizontal splits to develop from repeated shear stress. These tears are most common in the posterior horn. During flexion, the upper surface of the meniscus slides over the inferior surface, the inner border bulging inward.

vii. Isokinetic Exercise

Isokinetic Exercise is a dynamic resisted exercise at a constant speed or angular velocity as specified on the isokinetic machine. If the subject attempts to move as rapidly as possible, near maximal muscle force is exerted throughout the range of movement. The speed of movement cannot exceed the selected angular velocity. Since the resistance automatically accommodates to the exerted force, isokinetic exercise is also called "accommodating resistance exercise."[20]

A. Bucket-handle tear of medial meniscus with displaced portion lying in the intercondylar notch

B. Transverse laceration of lateral meniscus

C. Peripheral separation of meniscus in the posteromedial corner

D. Posterior horn "flap" tear of medial meniscus

E. Horizontal "cleavage" tear of posterior horn, lateral meniscus

FIGURE 4: Partial tears of the meniscus

The Cybex® II isokinetic system (FIGURE 5), including a pen recorder, was used to record both torque and range of motion.

viii. Torque

Torque is a measure of the turning effect of a force about some axis of rotation.[20] Torque equals the length of the lever arm, measured from the axis of rotation to the point of application of the force, multiplied by the component of force that is perpendicular to the lever arm.[21] Since it measures force through distance, the measurement unit is Foot-pounds or Newton-meters.

The amount of torque which a muscle produces depends on several factors including: the number of motor units activated, the muscle length, and the distance to the axis of rotation.[22,23]

ix. Acute Stage

In this study, the acute stage of inflammation was defined as the short and relatively severe course of tissue reaction which followed injury.[24] The time period for the acute stage of joint inflammation following complete ligament rupture may be several weeks.[25] Subjects with anterior cruciate ligament tears were not tested while in the acute stage after injury.

FIGURE 5: The Cybex® II isokinetic system

x. Swelling

Minimal swelling of the knee joint referred to the amount of joint fluid identified by a positive "wipe" test.[26] The examiner used her hand to stroke proximally two or three times along the medial aspect of the joint commencing below the joint line and moving as far as the suprapatellar pouch. She then used her opposite hand to stroke down the lateral side of the patella. A wave of fluid, if present, passed to the medial side of the joint and bulged just below the distal border of the medial side of the patella, indicating minimum swelling.

Moderate swelling of the knee joint was identified by a positive "patellar tap" test.[27] With the knee extended, a slight tap or pressure over the patella, by the examiner's finger, produced movement and a feeling of floating.

6. Delimitations

i. Only subjects diagnosed as having an anterior cruciate ligament injury, or an anterior cruciate ligament injury with a partial tear of medial or lateral meniscus were examined in groups I and II.

ii. Group I and group II subjects described a history of an audible "pop" at the time of the injury.

iii. Group I and group II subjects demonstrated a positive Anterior Drawer test with the tibia in

neutral, a positive Lachmann test, and a positive Pivot Shift test as outlined in the Operational Definitions.

iv. The following tests were negative in group I and group II subjects: valgus and varus stress tests, posterior drawer test, and rotary tests for posterolateral and anteromedial stability.

v. In group I and group II subjects, the injury was no longer in the acute stage, with no more than minimal effusion in the knee joint.

vi. Arthroscopic examination was performed and found to be positive for isolated anterior cruciate ligament tear in group I subjects.

vii. For the second group (group II), arthroscopic examination identified an anterior cruciate tear and a meniscal tear, and the meniscal fragment was removed in the same arthroscopic procedure.

viii. Group I and II subjects had not participated in treatment or rehabilitation programs.

ix. Group III subjects had no history of knee injury or surgery bilaterally, and were found to be free of signs and symptoms of pathology on knee examination.

x. All subjects were painfree and free of patellar crepitis during Cybex® II testing.

7. Limitations

i. Only subjects with anterior cruciate ligament tears and meniscal tears as diagnosed by one orthopedic surgeon were examined for groups I and II.

ii. The shape and amplitude of the recorded torque-angle curves in representing true isokinetic strength of the quadriceps and hamstring muscles were dependent on the accuracy of the torque recording system of the Cybex® II dynamometer, and the subject's ability to reproduce maximal effort.

iii. The results were dependent on the investigator to measure accurately the torque output.

iv. The isokinetic dynamometer (Cybex® II) was capable of testing in one plane of movement only. Recorded torque patterns did not reflect the rotational component of knee movement.

v. The study was restricted by the availability of subjects who had an accurate diagnosis, confirmed on arthroscopic examination by one orthopedic surgeon.

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CHAPTER 2

LITERATURE REVIEW

Damage to the anterior cruciate ligament may be the most common disabling problem in the athlete's knee.[1] Severe disability is often associated with disruption of the anterior cruciate ligament of the knee. Since the primary mechanism of stability for the knee joint is the complex of ligaments to which the anterior cruciate ligament belongs,[2] optimal rehabilitation after injury is of great concern. Muscle strength and coordination play an important role in the stability of the knee joint,[3] and can partially compensate for lack of ligamentous stability.[4] It has been found that patients who regained normal thigh circumference or actually hypertrophy the thigh muscles during rehabilitation after anterior cruciate ligament injury have better functional results than those with muscle atrophy.[5] It has been suggested that strong hamstring musculature may compensate for instability of the anterior cruciate ligament.[6]

Anatomical Relationships

The anterior cruciate ligament functions with the capsular structures, collateral ligaments and menisci to prevent anterior displacement of the tibia on the femur.[7,8] The ligament fibers consist of a posterolateral band and anteromedial band, which spiral, making a turn of forty-five to ninety degrees from origin to insertion. This spiralling allows for tension in some fibers of the ligament in every position of flexion and extension. In a position of full knee extension, the posterolateral component of the anterior cruciate ligament is tight, and the anteromedial band is loose. Thus the position for rupture of the posterolateral band is knee extension.[9,10] This rupture often occurs as the patient plants his foot to change direction or decelerate during hard running. As the knee moves into a position of flexion, the anteromedial component of the anterior cruciate ligament becomes tight and the posterolateral component becomes loose. Thus an anteromedial band tear is most likely to occur in a flexed knee position with a posterior-anterior displacement force on the tibia, such as a clipping injury in football. A total rupture can result if the force is great enough in either position to cause failure of both bands.

Jackson[9] has observed that in fifty-one per cent of all knees with anterior cruciate ligament injury, the ligament

is totally disrupted. Kennedy's[11] experiments with bone-ligament preparations to determine ultimate tensile strength of the anterior cruciate ligament demonstrated failure when the ligament was elongated twenty to thirty per cent of resting length. In a series of 1,000 knee problems seen by Gomes and Jackson,[12] 119 anterior cruciate ligament ruptures were diagnosed. This frequency is twelve per cent of injured knees.

Jackson reported the posterolateral band to be injured four times as frequently as the anteromedial band. He considered injury to the posterolateral band to be more significant because of its function as an anterior tibial restraint in a position of full knee extension, where the muscles have a mechanical disadvantage and therefore minimal control in stabilizing the knee joint.[9]

Isolated anterior cruciate ligament injuries are often difficult to diagnose because of the effectiveness of the secondary anterior tibial restraints, and the skill of the examiner. Use of diagnostic arthrography in recent years has identified many isolated anterior cruciate ligament injuries which were previously undiagnosed. The incidence of isolated anterior cruciate ligament injury is not yet known.

Any of the secondary restraints to anterior tibial movement can be injured in combination with the anterior

cruciate ligament. Meniscal attachments, especially those in the intercondylar fossa of the tibial condyle, are in close anatomical association with the anterior cruciate ligament. The medial meniscus attaches at the anterior horn to the anterior cruciate ligament, or just in front of it.[10] Both menisci serve to deepen the articular surfaces of the tibial plateau to compensate for lack of congruence between the femur and the tibia. They assist in preventing anterior-posterior movement of the tibia, particularly in load bearing.[10,13]

The anterior cruciate ligament stabilizes the lateral femoral condyle on the tibia during the screw-home mechanism in the knee.[14] The medial and lateral hamstring muscles act to reinforce the stability by preventing anterior tibial subluxation on the femur. Marshall et al[15] stated that the biceps femoris muscle played an important role in anterolateral stability of the knee as it progressed in flexion. They found that portions of the superficial and deep layers of the muscle acted in conjunction for strong anterior attachment on the lateral aspect of the tibia. In addition, the anterior expansion of the superficial layer extended forward, superficial to the lateral ligament, and blended with the anterior crural fascia forming a consistently strong section of the insertion. Deep fibers of biceps femoris muscle joined the iliotibial band for a

fibrous insertion, and helped keep it taut in various degrees of flexion. These authors reported the iliotibial band to be most taut in ten to thirty degrees of flexion.[15]

The semimembranosus muscle sends attachments to the posterior joint capsule and forms a fibrous expansion over the popliteus muscle, in addition to its principle insertion on the medial tibial condyle.[16] The medial and lateral heads of the gastrocnemius muscle aid the stability of both the posterolateral aspect of the knee and the arcuate complex,[1] and assist knee flexion.

During deceleration and change of direction, as occur in athletic competition, the hamstring muscles and the anterior cruciate ligament appear complimentary in function, while the quadriceps muscles are antagonistic.[17] Feagin et al[17] suggested that hamstring muscle weakness relative to the quadriceps muscle strength might actually predispose the athlete to anterior cruciate ligament sprain.

Mechanics After Injury

After injury to the anterior cruciate ligament, massive knee joint effusion occurs over a twenty-four hour period. In this acute stage, the anterior drawer sign is often negative due to hamstring muscle spasm.[17] Facilitation of the hamstring muscles and inhibition of the quadriceps muscles are frequently observed by the therapist at this

time. The stability exhibited on initial examination may continue over several months, but progressive disability ensues. Fetto and Marshall[18] described a predictable natural history typified by a course of progressive knee dysfunction and deterioration. This course was generally agreed upon by most authors, and has been well documented, particularly by Jobe.[19] In a follow-up study of patients with anterior cruciate tears, ten years after injury, McDaniel et al[5] found a definite progression to varus or valgus laxity, anterior laxity, rotary instability and meniscal tear. Only one knee in the series of fifty-three was reported to be completely stable to anterior and rotary stresses. They reported that the best functional results, with least progression of pathology, were observed in patients with thigh muscle hypertrophy.

Ellison[20] stated that in the chronically unstable knee with anterior cruciate deficit, if the lateral structures are not injured acutely, they secondarily stretched. According to his observations, the late development of the positive subluxation test (pivot shift test), in the previously negative knee, was a classic illustration of the dynamic nature of anterior cruciate ligament instability. Biomechanical studies by Butler et al[7] demonstrated that soft tissue secondary restraints to the anterior drawer movement often stretched out when the primary restraint

was torn and would no longer provide knee stability under functional forces of activity.

When the anterior cruciate ligament is initially sprained, there can be significant deformation of its fibers without total tearing, but anterior restraint is not entirely lost.[11,19] With repeated rotational injuries, the integrity of the ligament is progressively lost if the anterior forces are great enough. The medial femoral condyle begins to ride over the posterior horn of the medial meniscus producing degenerative-type tears of the meniscus. The rotary guidance given by the anterior cruciate ligament is lost; and the tibia is not carried to its normal external rotary screw-home position in terminal extension. The tibia is in relative internal rotation at full extension, and with repetitive forces in this position, the lateral compartment and particularly the iliotibial band become stretched. Instability usually occurs between twelve and eighteen months after the initial injury.[19]

Incidence of combined anterior cruciate injury and meniscal damage without further soft tissue damage is not known. Jackson[9] reported that in a group of forty-three patients with anterior cruciate ligament damage, thirty-seven had associated meniscal disorders. He reported that two-thirds of these patients were improved by arthroscopic menisectomy, removing the fragment and

retaining the bulk of the meniscus for its function as a secondary restraint. In this group, the majority of the tears were small flap tears of the meniscus.

Tamea and Henning[20] and Johnson[21] have described the alteration in joint mechanics which produces increased anterior shear force in the knee joint. By analyzing changes in instant centers of motion in the knee, both investigators defined a normal combination of rolling and sliding motions occurring at the knee joint surface. Pure rolling does not occur in the normal knee. However, in the presence of anterolateral instability, it occurs as the instant center crosses the joint line.[20] This alteration takes place within the first twenty degrees of knee extension. Potential degenerative changes in the joint are indicated with repeated entrapment of the meniscus.

Clearly, the injured anterior cruciate ligament needs assistance in its function as a guidance mechanism for rotary control of the 'screw-home' mechanism, and to prevent further displacement of the tibia on the femur.[22] The dynamic nature of the instability demands that this assistance be given early and in relation to the degree of disability.[22] Understanding of the dynamics of the rotary instability and knowledge of the exact deficit is the basis of treatment. The deficit varies according to the initial mechanism of injury. If more than the anterior cruciate

ligament is injured, various degrees of anterolateral, anteromedial, posteromedial, and posterolateral rotary instability will complicate the dynamics from the onset.[23]

Rehabilitation Programs

In the author's experience, rehabilitation after anterior cruciate ligament rupture concentrates initially on knee flexion and ankle movements, as well as hip extension and abduction. Quadriceps muscles are strengthened in the later stages with progression to proprioceptive training. These rehabilitation programs, commonly used by physical therapists, are based largely on clinical experience and knowledge of the disability, rather than the results of laboratory controlled experimentation and data confirming the efficacy of treatment.

Ellison[22] stated that a knee with anterior cruciate ligament impairment, even to a minimal degree, demanded protection in the immediate post-convalescent period. He and his workers routinely conducted a Cybex® II isokinetic evaluation of extensor, flexor, internal rotator and abductor power about the knee, and then instituted hamstring muscle exercises until peak strength of the hamstring muscle approached or equalled that of the quadriceps muscles. At that point, both muscle groups were strengthened as rapidly as possible. Ultimately, the quadriceps muscle demonstrated

greater torque capability as normal strength patterns were regained. Simultaneous abduction exercises were carried out to strengthen the tensor fascia lata and the iliotibial band, since these structures resisted anterolateral tibial movement. Ellison's [22] description was the only one available in the published literature concerning rehabilitation of anterior cruciate ligament rupture without surgical repair or reconstruction.

Description and debate concerning the optimal treatment by surgical repair and reconstruction of the anterior cruciate ligament is found in the literature, and has been well summarized by Collins[1] and James.[24] Within these surgical reports, rehabilitation was frequently noted to be a very important part of the repair.[1,15,25] However, precise description of the rehabilitation program was only minimally addressed. Programs consistently involved strengthening of the knee flexor muscles in the initial stages. After repair, Jobe[19] first emphasized the hamstring musculature, then the triceps surae muscles, and when good strength was achieved in the triceps surae muscles, the quadriceps muscles were exercised. This method was frequently followed for patients with and without surgical repair of the ligament.

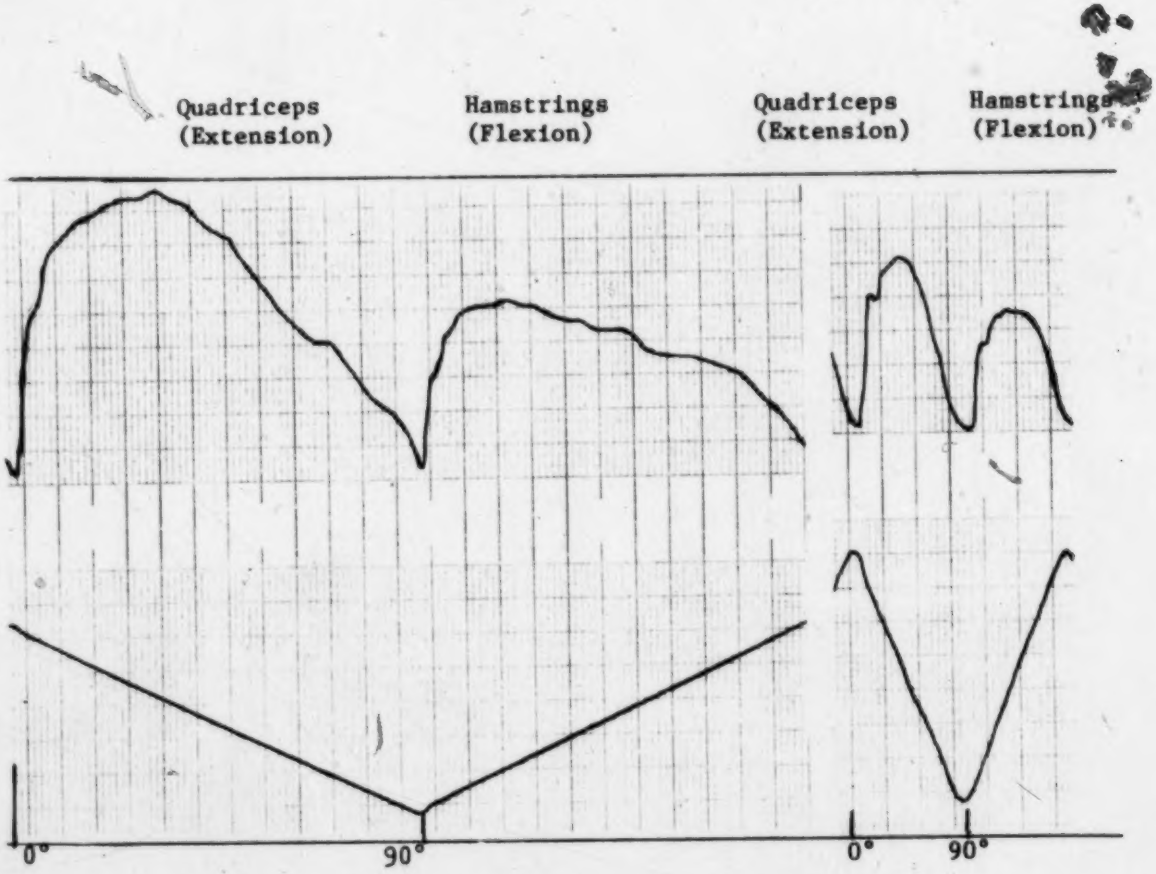
In a long-term study of patients five to ten years after anterior cruciate ligament reconstruction, Arvidsson

et al[6] observed that poor function of the anterior cruciate ligament resulted in poor quadriceps function, but that the knee flexors were not significantly impaired when compared to the normal leg. He gave two possible explanations for this observation. First, the knee extensors via the patella and patellar tendon are more intimately related to the knee joint and thus affected by joint pain and instability. Although the semimembranosus tendon sends attachments into the posterior joint capsule, and the biceps femoris muscle inserts in part into the lateral collateral ligament, the hamstring muscles are not as closely related to the knee anatomically as are the quadriceps muscles. Secondly, patients with anterior cruciate ligament instability are compensating with stronger hamstring muscles. Studies have shown a relationship between capsular distension from knee effusion and quadriceps inhibition.[26,27] Changes in hamstring muscle activity in response to knee joint pain, effusion or pathology have not been described.

Rehabilitation of knee muscles with isokinetic exercise is not detailed in programs described for anterior cruciate ligament injuries.[6,22,28,29] Jones[30] stated that muscle testing using an isokinetic apparatus may be done on the initial evaluation in mild anterior instability problems without significant pain and swelling. With more significant anterior instability, the anterior shear forces

created by the strong pull of the quadriceps muscles during isokinetic extension were thought to create further swelling, pain, and capsular stretching. Malone[28] stated that with chronic ligamentous instability causing anteromedial and anterolateral instability of the tibia, full arc isokinetic exercise may tend to cause subluxation of the tibia anteriorly and increase the instability. He also stated that posterolateral instabilities should not be taken to the final ten degrees of knee extension because it allowed lateral tibial rotation against the posterolateral part of the capsule.

The healing and maturation processes of ligament tissue takes much longer than originally thought. Noyes et al[31] studied the effects of immobilization and reconditioning on animals, and noted only partial recovery of tensile properties of the injured anterior cruciate ligament at five months after resumed activity, while complete recovery required up to one year. These studies indicate that resistance exercise, including isokinetic exercise should be initiated only after a period of time for healing has been allowed. The period of time during which these tensile stresses must be limited has not been determined as yet.



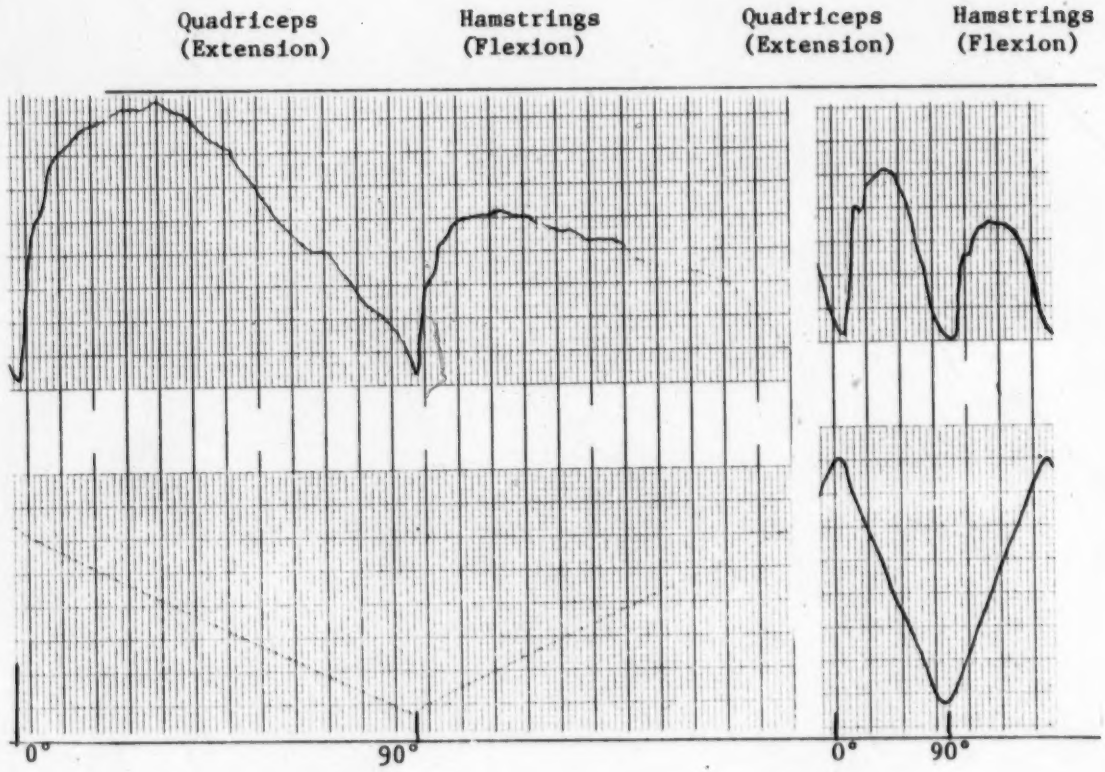
A. Angular velocity of 30 degrees per second

B. Angular velocity of 180 degrees per second

FIGURE 6: Pen recordings of torque (top) and range of movement (bottom) for isokinetic knee extension and flexion. Paper speed of fifty millimeters per second. (0° is a straight leg).

Isokinetic Exercise

Observation of normal isokinetic torque values of the knee reveals that the quadriceps muscles produce greater torque than hamstring muscles. This difference decreases as the speed of the exercise is increased (FIGURE 6). With higher angular velocities, both muscle groups produce less torque.[32,33] Wyatt and Edwards[34] suggested that at speeds greater than 300 degrees per second, the hamstring torque output may exceed the quadriceps torque output. Studies by these authors showed the hamstring muscles to produce seventy-two per cent of the quadriceps output for males and seventy-one per cent for females, at an angular velocity of 60 degrees per second. Moffroid et al[32] reported the ratio to be fifty per cent at 60 degrees per second. At test speeds of 180 degrees per second, Wyatt and Edwards[34] found the ratios to be eighty-five per cent and eighty-three per cent for males and females respectively. Campbell and Glenn[35] report ratios of sixty-eight per cent, and eighty per cent, for thirty degrees per second, and 180 degrees per second respectively. The dominant knee has been reported to produce significantly greater torque output than the non-dominant knee,[36,37] a point of major concern in rehabilitation, where the objective is not necessarily to equalize the muscle strength in both legs.

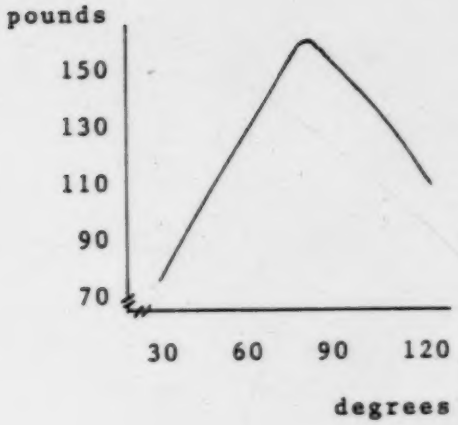


A. Angular velocity of 30 degrees per second

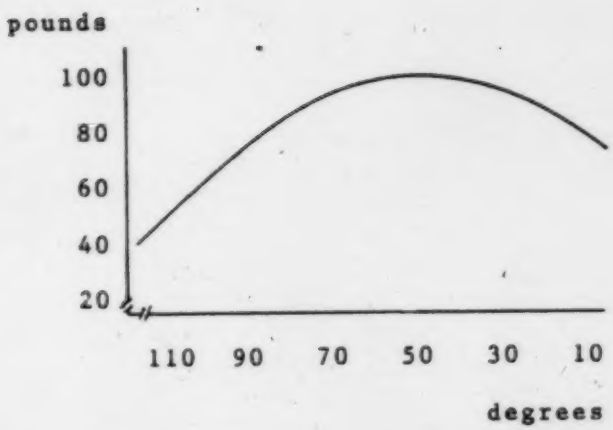
B. Angular velocity of 180 degrees per second

FIGURE 6: Pen recordings of torque (top) and range of movement (bottom) for isokinetic knee extension and flexion. Paper speed of fifty millimeters per second. (0° is a straight leg).

With isokinetic testing, the configuration of the torque curves at lower speeds (below 100 degrees per second) for knee flexion and extension are similar to the force curves described by Williams and Stutzman.[38] They obtained their force curves by plotting the values of maximal isometric contractions at points along the arc of motion (FIGURE 7). The described force curves defined peak torque at approximately sixty-three degrees for knee extension, and approximately forty-five degrees for knee flexion (full extension defined as zero degrees). However, as the angular velocity is increased, and the muscle is required to shorten at a faster speed, the peak torque tends to occur later in the range.[37,39,40,41] This change indicates that in evaluating the muscle contraction through a range of motion, the shape of the torque curve must be considered in relation to the speed of the contraction. Studies by Moffroid et al,[37] Osternig,[39] and Scudder,[40] describe this change in angle of peak torque, but could not be compared because of differences in methodology and angular velocity.



A. Knee extension



B. Knee flexion with hip flexed

FIGURE 7: Force curves:
Values of maximal isometric contractions at points along the range of motion.
From William, M.; Stutzman, L.: Strength Variation through the range of motion.
Phys Ther Rev 39:145, 1959.

Peak torque values during isokinetic knee flexion and extension in normal subjects vary with age, sex, sports participation and type of sports of participation. To report peak torque values, testing situations must be specified, because values will vary with altered subject position,[42,43] amount of warm-up[44,45,46] and speed of movement.[32,36,44]

Moffroid et al[37] reported peak torque values of 105±6 foot-pounds for the quadriceps muscles and 51±4 foot-pounds for the hamstring muscles when tested at a velocity of 22.5 degrees per second. Their group consisted of twenty subjects, age range eighteen to thirty-one years, both sexes included, dominant leg only.

Wyatt and Edwards[34] report peak torque values of 97±14 foot-pounds for the quadriceps muscles, and 75±14 foot-pounds for the hamstring muscles at an angular velocity of 180 degrees per second. Their subjects consisted of fifty males and fifty females and ranged in age from twenty-four to thirty-four years. Values reported average the dominant and non-dominant legs.

Campbell and Glenn[35] reported peak torque values of 195 and 132 foot pounds for flexion and extension respectively at a velocity of thirty degrees per second, and 111 and 83 foot pounds for flexion and extension respectively at 180 degrees per second. These values represent the uninvolved

legs of their subjects with injured knees, age range thirteen to seventy-one years.

No quantitative change in the angle of peak torque, or in the pattern of the torque curve, has been described in response to knee pathology which may alter the neuromuscular control or biomechanics of movement.

Conclusion

The response of the knee flexor and extensor muscles to anterior cruciate ligament rupture has received minimal investigation. Functional anatomy suggests that the hamstring muscles, biceps femoris in particular, can reinforce the action of the anterior cruciate ligament as a primary restraint to prevent anterior tibial subluxation on the femur. Patients with knee ligament instability and fair functional capability demonstrate quadriceps weakness, although hamstring strength is often normal. Patients with anterior cruciate ligament instability often have better function with hypertrophy of thigh muscles.

Damage to the primary restraint of anterior tibial movement on the femur may alter the mechanics of active knee joint movement. Additional damage to a secondary restraint, such as a meniscus, will augment this change in joint mechanics. Such change may be reflected in the action of the muscles of knee flexion and extension. Isokinetic

exercise is often used in the later stages of rehabilitation for patients with damage to the anterior tibial restraint mechanisms, although altered joint mechanics may result in torque-angle relationships which are different from the normal.

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CHAPTER 3

METHODS AND PROCEDURES

1. The Experimental Procedure

i. Introduction

A two-channel isokinetic dynamometer (Cybex® II) was used to record the torque pattern of the quadriceps and hamstring muscles during reciprocal isokinetic contractions (FIGURE 8). Torque and angle of knee motion were recorded at angular velocities of a) thirty degrees per second, and b) one hundred and eighty degrees per second, for both knees.

The initial four injured subjects, and two additional injured subjects who were not included in the study, were tested at various angular velocities from thirty to three hundred degrees per second, in order to determine the two best velocities for testing in the study. Subjective examination of the torque patterns indicated that at velocities of thirty, and one hundred and eighty degrees per second, the greatest difference in torque patterns occurred.

FIGURE 8: Experimental setting

The two pilot subjects were also tested to standardize the arm position, and hip angle. Arms positioned across the chest consistently allowed less torque output of knee extensor and flexor muscles and less muscle substitution than arms positioned with hands grasping the handles on the seat. Therefore, it was decided to position the hands across the chest for testing. It was found that a hip angle of eighty degrees (zero degrees being the position of the leg in line with the trunk in a coronal plane) gave the greatest torque output during both knee extension and flexion (FIGURE 9). These positions were consistent with previous studies.[1,2,3]

ii. Subjects

Seventeen untrained subjects, mean age 30.0 years, volunteered for group I (n=7) and group II (n=10). They had been seen by an orthopedic surgeon in his practice. These subjects had one normal uninjured knee, and one injured knee, diagnosed as total rupture of the anterior cruciate ligament with or without a meniscus tear. The criteria for diagnosis have been outlined in Operational Definitions. The average time since injury was 15.4 months for group I (isolated anterior cruciate ligament tear) and 31.5 months for group II (anterior cruciate ligament tear and partial meniscus tear).

FIGURE 9: Subject seated for testing with a hip angle of eighty degrees

Fifteen untrained volunteer subjects, mean age 33.0 years, with no history of major knee injury, were tested bilaterally in random order of presentation as group III, for comparison with the injured groups.

The subjects had no previous experience with the Cybex® II dynamometer. They were instructed not to participate in strenuous activity on the day of the test, prior to the test, to avoid fatigue. Prior to testing, the subjects received an explanation of apparatus and testing procedures (APPENDIX A), and completed several warm-up efforts.

iii. Dynamometer

Accommodating resistance was provided by a Cybex® II , manufactured by Lumex, Inc., Bay Shore, New York, 11706. This isokinetic dynamometer also measured the torque developed throughout the range of extension and flexion at the selected angular velocities. Torque and range of motion were recorded by the two channel pen recorder component, at a chart speed of fifty millimeters per second. A one hundred and eighty foot-pound scale was used on the recorder. The General Purpose Amplifier on the range of movement channel, was preset such that ninety degrees of knee flexion provided the lower baseline. The Cybex® II was calibrated daily throughout the study (APPENDIX B). A damping control setting of 2 was used throughout all test sessions.

iv. Procedure

Each informed subject was seated in the testing chair with the knee at ninety degrees of flexion and the axis of rotation of the dynamometer aligned with the lateral femoral condyle of the knee joint. The hip was maintained at an angle of eighty degrees with the trunk supported by the back rest and additional pads if necessary.

Stabilization straps were used to secure the thighs, pelvis, and shoulders in order to limit extraneous movements and muscle substitution (FIGURE 10). The shin pad and strap of the lever arm were secured above the malleoli to allow free range of ankle motion without shoe or sock. A block prevented movement beyond ninety degrees of flexion. Subjects were positioned with their arms across their chests during testing.

The subjects were then instructed to perform one trial of three reciprocal submaximal isokinetic contractions[4] through extension and flexion, and then one trial of three reciprocal maximal isokinetic contractions[5] for practice at the selected angular velocity, before testing. A one-minute rest period was given before the test period for recovery after the practice procedure.[6]

The test consisted of one trial of three maximal reciprocal isokinetic contractions of the knee extensors and flexors, beginning with the normal leg for groups I and II.

FIGURE 10: Stabilization strap placement during isokinetic testing (the arms were positioned across the chest during the test efforts)

Group I and group II subjects were tested in the order in which they volunteered, considered to be a random order. With the knee flexed to ninety degrees, the subjects performed maximal isokinetic contractions, raising the lower leg to a position of their maximum knee extension, and then pulling down as hard and as fast as possible from extension to the starting position of ninety degrees of flexion. As the result of the thickness of the Cybex® II chair seat, ninety degrees was the maximum excursion in flexion. This sequence was repeated three times without rest for the test trial. During all test efforts, the subjects watched the torque dynamometer of the Cybex® II and attempted to exert maximum torque. The tester used the same brisk commands, for maximal effort, throughout the study. Identical procedures were followed to test the opposite leg, and then each subject was asked to ride the stationary bicycle for approximately two or three minutes, using a low tension setting. This continuation of low intensity exercise was made available to enhance removal of waste materials accumulated in the legs during the brief maximal intensity exercise required for testing, thereby minimizing subsequent muscular discomfort.

2. Data Presentation and Analysis

Analysis was based on data measured and calculated from the pen recordings (FIGURE 11). Measurements were made from

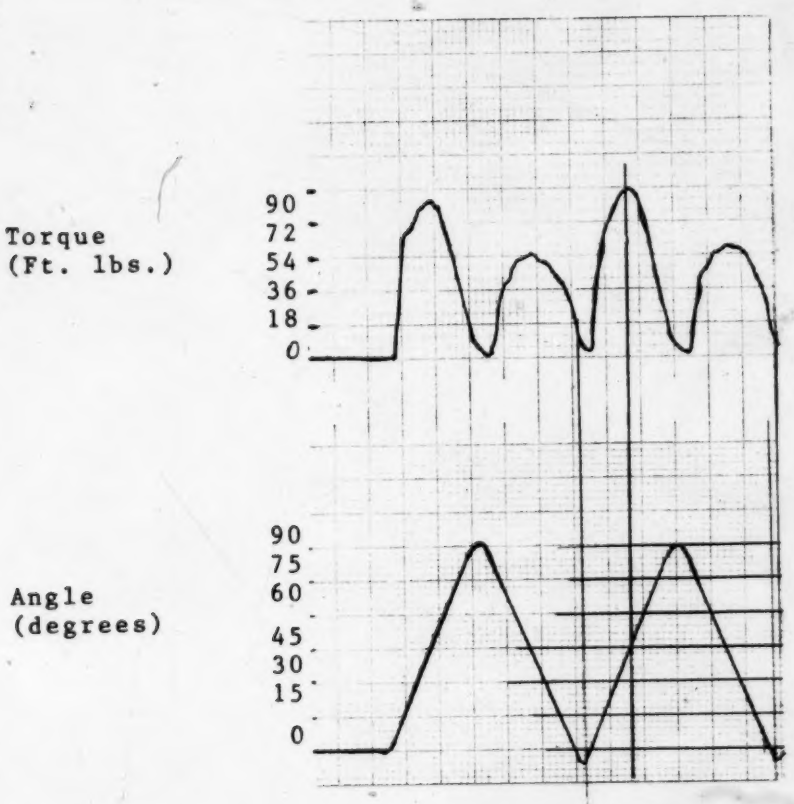

FIGURE 11: Pen recording of torque and angle curves: measurements were made at increments of fifteen degrees of movement, and at the angle at which peak torque occurred.

the illustrations of the torque and angle curves to give values for: a) the peak torque at increments of fifteen degrees of knee movement; b) the angle at which peak torque occurred; and c) both a) and b), above, during flexion and extension of the knee, at angular velocities of thirty, and one hundred and eighty degrees per second. Correction for gravity was not used. Reliability coefficients were established for measurements of torque and angle using one subject, and are presented in APPENDIX C. For comparison with groups I and II, data from group III were divided into values for weaker and stronger legs, and related to the injured and uninjured legs of groups I and II respectively. Raw data are presented in APPENDIX D.

Mean values of torque at thirty, forty-five, sixty, and seventy-five degree angles of knee extension and flexion were determined as the representative of the torque-angle relationships or patterns of torque for all three groups. Differences in the torque values between the weaker, or injured, legs and the stronger, or uninjured, legs were calculated for both angular velocities and expressed as difference scores. A four-way analysis of variance on difference scores (three groups, with repeated measures over two types of motion, two angular velocities and four angles), as discussed by Edwards,[7] was used to examine the difference scores for pattern of torque. Additional clarification of the four-way analysis of variance procedure

is contained in APPENDIX E.

Mean values of angle of occurrence of peak torque in flexion and extension were calculated for all three groups. Differences between the angle of occurrence of peak torque for the weaker, or injured legs, and the stronger, or uninjured legs, were calculated for both angular velocities and expressed as difference scores. A three-way analysis of variance on diffence scores (three groups with repeated measures over two types of motion, and two angular velocities) was used to examine the difference scores for angle of occurrence of peak torque.[8]

A Tukey multiple comparison analysis, as described by Hopkins and Glass,[9] was used on the mean values of the raw scores for angle of occurrence of peak torque. Mean values of raw scores for injured and uninjured, and weaker and stronger legs were compared and analyzed for signifance ($p<0.05$) within groups and between groups. This additional analysis was used to examine the significant group difference found in the three-way analysis of variance on difference scores for angle of occurrence of peak torque.

A Tukey multiple comparison analysis was also used to examine mean values of raw scores for peak torque. Values for injured and uninjured, and weaker or stronger legs were compared and analyzed for significance ($p<0.05$) within groups, and between groups.

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CHAPTER 4

RESULTS

The major purpose of the study was to determine if patterns of torque for knee flexion and extension differed between the injured legs and the uninjured legs of subjects in groups I (isolated anterior cruciate ligament injury) and II (anterior cruciate ligament injury with partially torn meniscus), and secondly, to determine if a similar difference between weak and strong legs in a control group, group III was present. Results and discussion are based on the patterns of torque as measured at fifteen degree increments, and the angles of occurrence of peak torque for knee flexion and extension at the angular velocities of thirty and one hundred eighty degrees per second. Additional information on peak torque values was also gathered.

TABLE 1 shows the age and sex characteristics for each of the three groups. TABLES 2 and 3 illustrate mean data for angle of occurrence of peak torque and values of peak torque, while TABLES 4 and 5 illustrate the significant comparisons observed following the Tukey tests. TABLES 6 and 7 summarize the difference scores (uninjured-injured or

TABLE 1

Age and Sex Characteristics for
Injured and Control Groups

	Group		
	I n=7	II n=10	III n=15
Number of subjects: male	7	7	11
Number of subjects: female	0	3	4
Mean age (years): (SD)	29 (10)	30 (7)	32 (6)
Age range (years)	24 - 41	21 - 51	22 - 44
Time since injury (months)	15.4	31.5	

TABLE 2

Mean Values of Raw Scores for Angle of Occurrence of Peak Torque
(Used with Tukey Test on Raw Scores, see TABLE 4)

		Angular Velocity			
		30°/sec.		180°/sec.	
		Type of Motion			
		Flexion	Extension	Flexion	Extension
GROUP I	Injured	33* (8)+	66 (6)	48 (13)	50 (6)
n=7	Uninjured	29 (10)	67 (6)	49 (13)	51 (4)
GROUP II	Injured	33 (7)	65 (12)	44 (9)	51 (6)
n=10	Uninjured	39 (5)	72 (5)	49 (10)	53 (6)
GROUP III	Weaker	28 (9)	67 (8)	38 (13)	51 (9)
n=15	Stronger	29 (5)	66 (8)	39 (12)	51 (6)

* Measured in degrees of flexion, complete knee extension = 0°

\+ (SD)

TABLE 3

Mean Values of Raw Scores of Peak Torque
(Used with Tukey Test on Raw Scores, see TABLE 5)

		Angular Velocity			
		30°/sec.		180°/sec.	
		Type of Motion			
		Flexion	Extension	Flexion	Extension
GROUP I	Injured	90* (13)+	121 (27)	59 (11)	75 (16)
n=7	Uninjured	94 (9)	132 (17)	72 (7)	79 (6)
GROUP II	Injured	91 (31)	146 (51)	63 (21)	79 (21)
n=10	Uninjured	94 (30)	159 (46)	65 (19)	87 (18)
GROUP III	Weaker	104 (30)	155 (44)	71 (21)	90 (21)
n=15	Stronger	124 (49)	173 (46)	75 (22)	98 (29)

* foot-pounds torque (1 foot-pound = 1.36 Newton-meters)

\+ (SD)

TABLE 4

Significant Comparisons for Angle of Occurrence of Peak Torque Means During Knee Flexion and Extension Following Tukey Test on Raw Scores (see TABLE 2)

GROUP I	injured, extension at 30°/sec.	with	injured, extension at 180°/sec.
	uninjured, extension at 30°/sec.	with	uninjured, extension at 180°/sec.
	uninjured, flexion at 30°/sec.	with	uninjured, flexion at 180°/sec.
GROUP II	injured, extension at 30°/sec.	with	injured, extension at 180°/sec.
	uninjured, extension at 30°/sec.	with	uninjured, extension at 180°/sec.
GROUP III	weaker, extension at 30°/sec.	with	weaker, extension at 180°/sec.
	stronger, extension at 30°/sec.	with	stronger, extension 180°/sec.

$p<0.05$

TABLE 5

Significant Comparisons for Peak Torque Means
During Knee Flexion and Extension
Following Tukey Test on Raw Scores (see TABLE 3)

GROUP II	injured, extension at 30°/sec.	with	injured, extension at 180°/sec.
	uninjured, extension at 30°/sec.	with	uninjured, extension at 180°/sec.
GROUP III	weaker, extension at 30°/sec.	with	weaker, extension at 180°/sec.
	stronger, extension at 30°/sec.	with	stronger, extension 180°/sec.
	stronger, flexion at 30°/sec.	with	stronger, flexion at 180°/sec.

$p<0.05$

stronger-weaker) for the pattern of torque (measured at fifteen degree increments) and the angle of occurrence of peak torque respectively.

A computer program, DEST02, developed by the Division of Educational Research Services at the University of Alberta (DERS, 1981), was used to calculate test-retest reliability coefficients for one subject. Peak torque and angle measurements were repeated on five consecutive test days for the four test parameters (extension at thirty degrees per second, flexion at thirty degrees per second, extension at one hundred eighty degrees per second, and flexion one hundred eighty degrees per second). Cronbach's Alpha reliability coefficient was r=0.9996 for the peak torque measurements, and r=0.9997 for the angle of peak torque measurements. Test-retest raw data and the matrix of Pearson Product Correlation Coefficients for peak torque and angle measurements are contained in APPENDIX C. Because the test procedure was identical for all subjects, it is assumed that similar reliability existed for the remaining subjects.

Fourteen of the total thirty-two subjects did not extend one or both knees to a position of fifteen degrees of flexion (zero being the position of the femur in line with the tibia in a coronal plane) at an angular velocity of thirty degrees per second, despite verbal encouragement.

TABLE 6

Difference Scores (Uninjured-Injured or Stronger-Weaker):
Pattern of Peak Torque
(Used with Four-way ANOVA)

		Angular Velocity							
		30°/sec.				180°/sec.			
		Joint Angle							
	Motion	75°	60°	45°	30°	75°	60°	45°	30°
GROUP I	Flexion	2.0*	0.9	2.7	2.7	-1.9	10.4	21.6	24.7
	Extension	22.4	11.2	9.7	0.7	1.6	0.9	7.3	9.3
GROUP II	Flexion	-0.1	5.9	10.0	8.1	6.9	0.3	2.4	1.0
	Extension	-3.0	8.3	-1.2	2.7	19.4	10.0	3.7	8.2
GROUP III	Flexion	10.3	10.6	9.3	6.2	3.9	3.1	3.9	11.7
	Extension	10.5	18.3	9.9	8.3	13.1	6.8	7.7	10.6

* foot-pounds torque (1 foot-pound = 1.36 Newton-meters)

TABLE 7

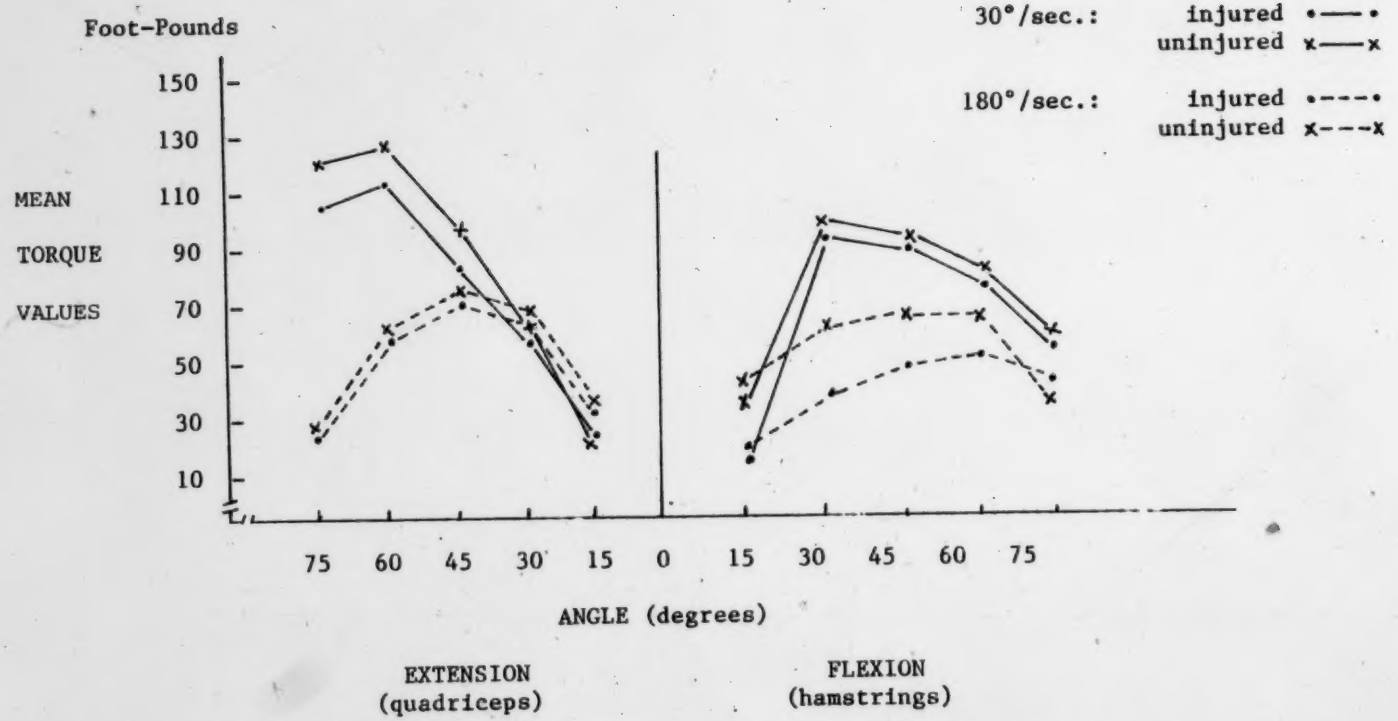
Difference Scores (Uninjured-Injured or Stronger-Weaker) for Angle of Occurrence of Peak Torque (Used with Three-Way ANOVA)

		Angular Velocity	
	MOTION	30°/second	180°/second
GROUP I	Flexion	-4.1*	1.1
	Extension	1.4	1.3
GROUP II	Flexion	5.0	3.8
	Extension	8.2	2.7
GROUP III	Flexion	1.0	-1.3
	Extension	0.7	0.3

* degrees

This decreased range of movement was attributed to tight hamstring muscles, and/or to the difficulty of the slow task. Therefore, some data for fourteen subjects were missing for measurements at the fifteen degree position and zero degree position at this slower angular velocity. For this reason, the torque measurements for the thirty, forty-five, sixty, and seventy-five degree positions were used to represent the pattern of torque in the statistical tests.

FIGURES 12 to 14 indicate that the pattern of mean torque measured at fifteen degree increments for injured or weak legs was similar to the uninjured and the stronger legs in all groups. A four-way analysis of variance (TABLES 8 and 9) to examine difference scores, injured or weak, minus uninjured or strong legs, through range of flexion and extension showed no significant difference between the groups. Because the injured leg was not always the weaker leg in groups I and II, some of the difference scores were negative values. A significant two-way interaction occurred between angular velocity (30° or 180°/sec.) and degree (joint angle) of the position. Three-way interaction occurred between group, angular velocity, and degree, and also between group, type of movement (flexion or extension), and angular velocity ($p<0.05$)(TABLE 9).



(sequence of movement is the same as that on the pen recordings)

FIGURE 12: Representative Torque-angle relationships of the knee for Group I

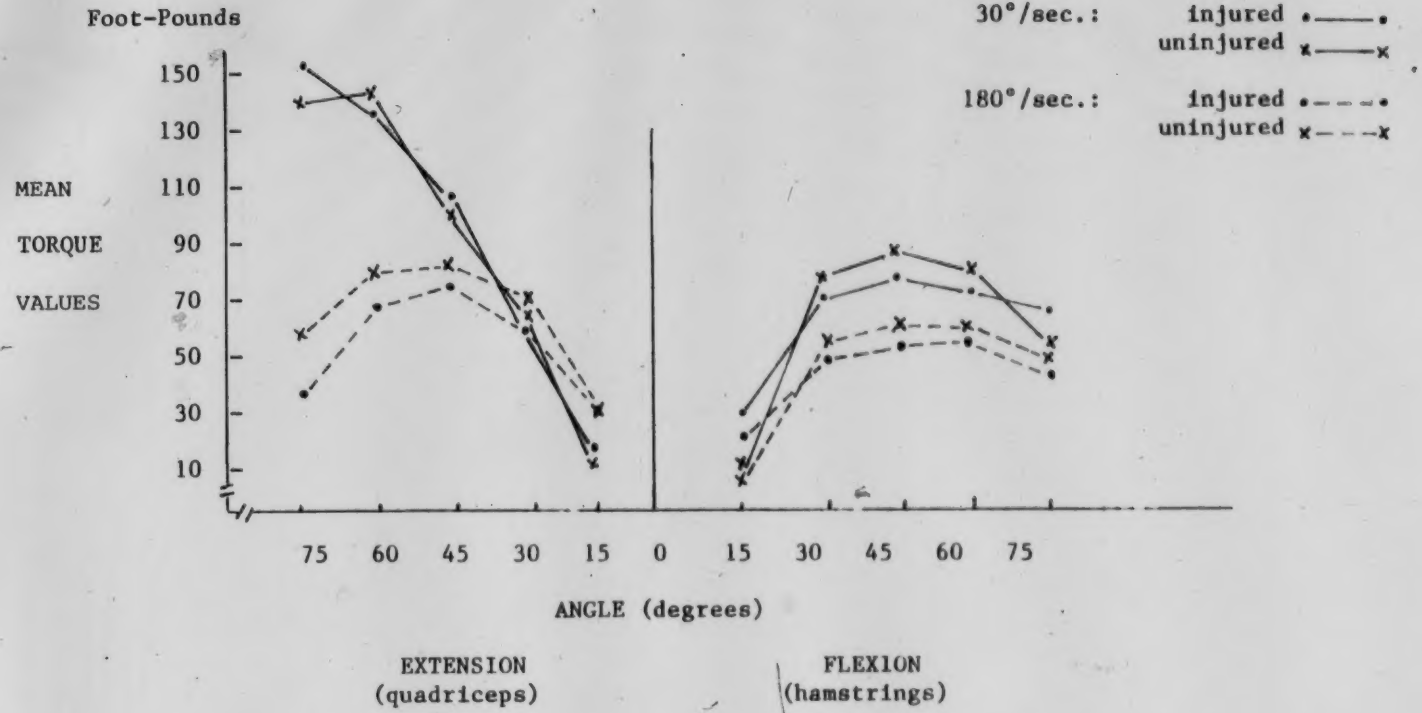
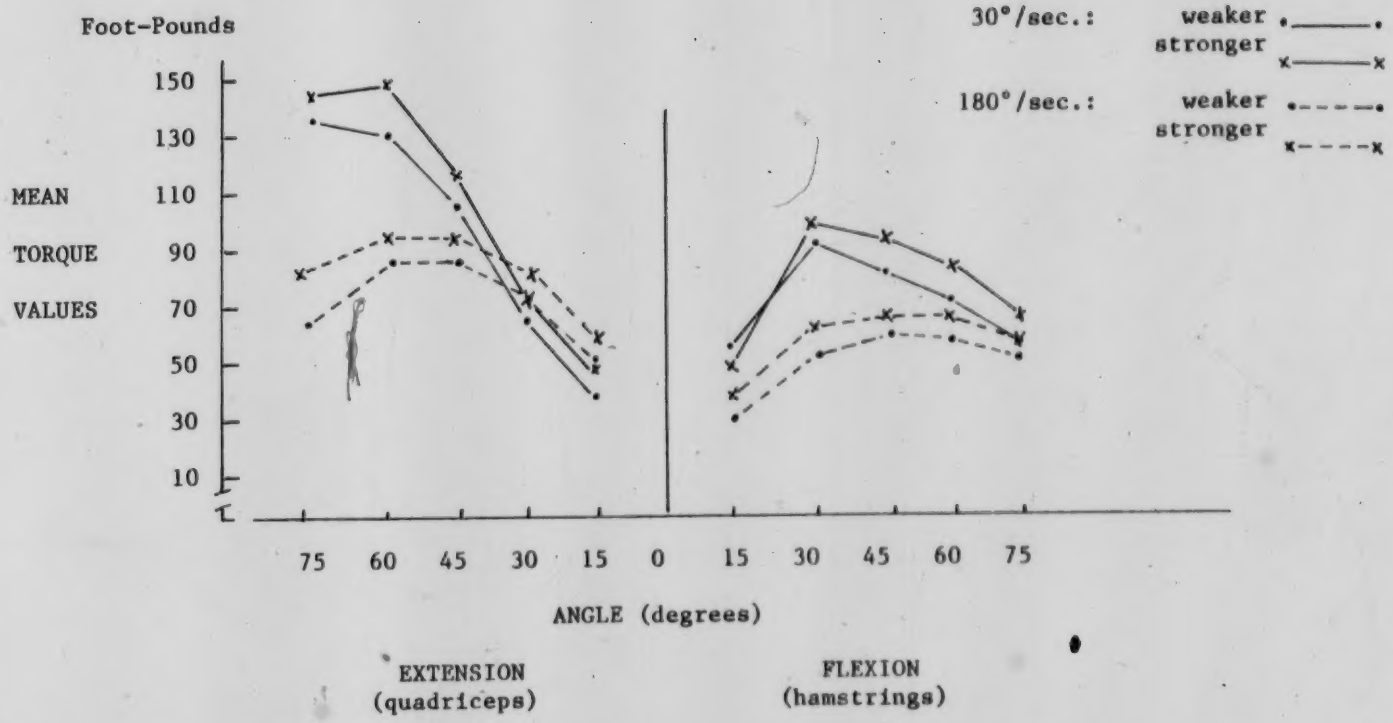


FIGURE 13: Representative Torque-angle relationships of the knee for Group II



(sequence of movement is the same as that on the pen recordings)

FIGURE 14: Representative Torque-angle relationships for Group III

TABLE 8

Pattern of Peak Torque Difference Scores
(Uninjured - Injured or Stronger - Weaker Legs)

	ANGULAR VELOCITY															
	30°/sec.								180°/sec.							
	TYPE								TYPE							
	EXTENSION				FLEXION				EXTENSION				FLEXION			
	JOINT ANGLE								JOINT ANGLE							
	30°	45°	60°	75°	30°	45°	60°	75°	30°	45°	60°	75°	30°	45°	60°	75°
GROUP I (n=7)	0.7	9.7	11.2	22.4	2.7	2.7	0.9	2.0	9.3	7.3	0.9	1.6	24.7	21.6	10.4	-1.9
GROUP II (n=10)	2.7	-1.2	8.3	-3.1	8.1	10.1	5.9	-0.1	8.2	3.7	10.0	19.4	1.0	2.4	0.3	6.9
GROUP III (n=15)	8.3	9.9	18.3	10.5	6.2	9.3	10.6	10.3	10.6	7.7	6.8	13.0	11.7	3.9	3.1	3.9

Foot-pounds torque
1 ft. lb. = 1.36 N.m.

TABLE 9

Pattern of Torque:
Difference Scores (Uninjured-Injured or Stronger-Weaker Legs)
at 15° Intervals (30°, 45°, 60°, 75°)
Four-Way ANOVA (Three Repeated Measures) Summary

Effect	MS	df	F	Probability
grand mean	29190.23	1	144.60	0.0000
group	765.07	2	1.49	0.2288
degree	20.28	3	0.10	0.9597
type	509.48	1	0.99	0.3207
speed	2.98	1	0.01	0.9394
group degree	110.72	6	0.55	0.7711
group type	109.75	2	0.21	0.8075
group speed	498.80	2	0.97	0.3807
type degree	509.24	3	2.52	0.0576
speed degree	557.18	3	2.76	0.0421*
type speed	8.16	1	0.02	0.8998
group type degree	181.50	6	0.90	0.4956
group speed degree	784.51	6	3.89	0.0009*
group type speed	1868.88	2	3.65	0.0290*
type speed degree	119.02	3	0.59	0.622
group type speed degree	35.66	6	0.18	0.9831
residual	201.86	351		
residual group type speed	512.27	117		

* denotes significance $p<0.05$

GROUP: I, II, OR III
DEGREE: 30°, 45°, 60°, or 75° position or joint angle
TYPE: FLEXION OR EXTENSION
SPEED or ANGULAR VELOCITY: 30°/sec. or 180°/sec.

A three-way analysis of variance (TABLE 10) to examine difference scores, uninjured minus injured legs of groups I and II, and strong minus weak legs in group III, in terms of the angle at which peak torque occurred, showed a significant difference between groups when averaged over type of motion and angular velocity ($p<0.05$). The mean difference score for group II was greater than that observed for group I, and greater than that observed for the control group (group III)(TABLE 11). This significant difference indicated that the angle of occurrence of peak torque, averaged over both angular velocities and over flexion and extension of the knees, differed significantly with injury to the anterior cruciate ligament and the meniscus. Tukey tests on raw data (TABLE 2) showed no significant difference between uninjured and injured values within group II, indicating that no one particular combination of movement and angular velocity was uniquely responsible for the overall significance.

Tukey tests to compare raw scores (TABLE 2) showed that the angle of occurrence of peak torque was significantly different at thirty degrees per second as compared to one hundred and eighty degrees per second, in all three groups, for both injured and uninjured legs, in extension of the knee. The raw scores for uninjured legs in group I were also significantly different between thirty degrees per second and one hundred and eighty degrees per second in

TABLE 10

Angle of Occurrence of Peak Torque:
Difference Scores (Uninjured-Injured or Stronger-Weaker Legs)
Three-Way ANOVA (Two Repeated Measures) Summary (see TABLE 7)

Effect	MS	df	F	Probability
grand mean	306.28	1	4.11	0.0448
group	348.11	2	4.68	0.0111*
type	94.57	1	1.27	0.2620
speed	26.28	1	0.35	0.5536
group type	12.04	2	0.16	0.8509
group speed	48.78	2	0.66	0.5212
type speed	13.78	1	0.19	0.6678
group type speed	57.86	2	0.78	0.4621
residual	74.86	116		

* denotes significance $p<0.05$

GROUP: I, II, OR III
TYPE: FLEXION OR EXTENSION
SPEED or ANGULAR VELOCITY: 30°/sec. or 180°/sec.

TABLE 11

Mean of Difference Scores for
Angle of Occurrence of Peak Torque
(Uninjured-Injured or Stronger-Weaker Legs)
Averaged over Angular Velocity and Type of Motion

GROUP	DIFFERENCE SCORES
I	-0.071*
II	4.670
III	0.233

* degrees

flexion ($p<0.05$). These significant differences are summarized in TABLE 4.

Tukey tests to compare raw scores of peak torque demonstrated significant differences between thirty degrees per second and one hundred and eighty degrees per second, in knee extension of injured and uninjured legs in group II and weaker and stronger legs in group III. The raw scores for the stronger legs in group III were also significantly different between thirty and one hundred and eighty degrees per second in flexion ($p<0.05$). These significant differences are summarized in TABLE 5.

CHAPTER 5

DISCUSSION

Isokinetic torque curves may be compared by relating the shape of the curves in terms of measurements of the torque at specific positions or angles in the range of movement.[1,2] Previous studies have also made comparisons by relating the angles at which maximum torque occurred.[1,3,4] The present study utilized both comparisons to determine if a change in isokinetic torque patterns following anterior cruciate ligament injury with or without a torn meniscus could be detected. The difference between the normal (group III) and the injured (groups I and II) was interpreted to represent a change attributable to the specific injury.

For the purpose of analysis, differences in the torque values and angles of peak torque, between the injured and uninjured legs of groups I and II, and the weaker and stronger legs of group III, were used. The use of difference scores eliminated the necessity of using a five-way analysis of variance to examine the patterns of torque. It also decreased the variability between individual subjects and minimized the effect of leg dominance. This increased the power of the statistical test because, with a lower standard deviation, there is a greater likelihood of finding significant differences, if

they exist.

In this study, torque curve patterns for normal and injured legs of groups I and II were related to strong and weak legs respectively, of the control group (group III), while the issue of leg dominancy was not addressed. Other studies have used dominancy to distinguish differences between legs in testing isokinetic torque.[2,5,6]

In the present study, the author assumed that dominancy of the lower extremity is identical to that of the upper extremity. Two of seven subjects in group I, and eight of ten subjects in group II, injured their dominant leg, introducing an additional variable if raw scores were used for analysis.

Pattern of Torque

The results of the statistical testing of the difference scores between injured and uninjured legs were consistent with the null hypothesis that torque-angle relationships produced during the maximal voluntary isokinetic contraction of the hamstring and quadriceps muscles at specific angular velocities are the same for both legs when averaged over group, type of motion, and angular velocity. The change in mean torque at fifteen degree increments of knee flexion and extension between the injured and uninjured legs is similar to the expected difference between strong and weak legs in a normal group, as seen in group III.

The injured subjects (mean age: 30 years) in both groups I and II had returned to full function and were painfree in their normal activities. They were well motivated for the test, and appeared conscious of performing well with the injured leg to demonstrate their progress since the arthroscopy procedure. This high motivation may have accounted in part for the similarity in the difference in patterns of torque between injured and uninjured legs in groups I and II, and weak and strong legs in group III. In addition, it is possible that compensatory changes involving an increase in muscle strength had occurred in the normal uninjured legs of groups I and II, since the time of injury to the contralateral limb. Such changes in the uninjured limb would have influenced the difference scores which were examined, by increasing their magnitude.

Since measurements of torque were made at fifteen degree intervals of movement to describe the patterns of torque, it is possible that some alteration in the normal pattern, due to momentary pain or inhibition, took place within the fifteen degree intervals and was not measured. If there was a true difference between groups, the difference could not be detected using the present methodology.

The significant second order interaction (between angular velocity and joint angle), and third order interactions (between group, angular velocity and type of movement, and between group, angular velocity, and joint

angle) confirmed the expected differences in torque values through range of movement at different angular velocities which have been previously described.[1,4,6] The representative torque-angle relationships illustrated in FIGURE 6 have characteristics previously described in other studies.[1,2,4,6,8] As the velocity of isokinetic exercise increased from thirty to one hundred and eighty degrees per second, the torque output at all angles in the range of flexion and extension decreased. This finding is well documented.[1,4,6,8,9] As the angular velocity increased, a smaller relative decrease in the flexor torque as compared to extensor torque was evident. This finding is in agreement with observations by Moffroid,[2] Richards[6] and Murray[10]. Overall, the torque patterns of groups I and II are considered to be normal.

The configurations of the torque-angle patterns for an angular velocity of thirty degrees per second follow the pattern of the force variations through the range of motion for knee extensors and knee flexors, as described by Williams and Stutzman.[11] They plotted load force values of maximal isometric contractions (see FIGURE 7) and found the highest torque values, at approximately sixty degrees during knee extension and forty-five degrees during knee flexion. Scudder[1] compared specific points in the arc of motion during isokinetic efforts with corresponding isometric torque values and found that the shape of the curves were similar, although at all points during isometric effort, the

torques were greater than corresponding isokinetic values. He tested at slow speeds (three to fifteen revolutions per minute).

Angle of Occurrence of Peak Torque

The point in the arc of motion at which peak torque is generated is dependent on the speed of motion.[1,2,3,6] Peak torque occurs earlier in the range of flexion and extension at slower speeds. This finding has been attributed to a possible lag or delay in exciting the contractile elements of the muscle at higher speeds,[2] or the time required for momentum of the leg to overcome inertia.[1] Reported angle of occurrence of peak torque varies from study to study,[1,2,3] suggesting changes in methodology, such as differences in subject age, positioning, and warm-up could be major contributory factors.

In the present study, analysis of variance for mean values of difference scores of angle of occurrence of peak torque (uninjured minus injured), when averaged over velocity and motion, demonstrated that group II was significantly different than groups I and III ($p<0.05$) (see TABLE 11). Averaging the mean values of two factors (velocity and direction of motion) for analysis, demonstrates a trend toward a change in angle of occurrence of peak torque in group II which was not apparent when mean values of raw scores (TABLE 2) were examined in the Tukey multiple comparison analysis. This result indicates a

general trend in terms of a change in angle of peak torque in group II which cannot be identified by a specific velocity or direction of movement, but requires testing of both legs at two angular velocities and in two motions.

Mean values for difference scores for angle of occurrence of peak torque were similar for groups I and III when averaged over angular velocity and type of motion (TABLE 11). The value for group II was significantly different from the values for groups I and III. Group II subjects differed in that the injured knees had minor meniscal damage with tears removed by arthroscopic surgery, and mean time since injury was longer by 16.1 months. Subjects in both groups I and II had total tears of the anterior cruciate ligaments, but group I had no meniscal damage, and the length of time since injury was shorter than group II.

The menisci are secondary stabilizers for the anterior movement of the tibia on the femur.[13,14] Literature concerning ligamentous restraints to anterior drawer movement are plentiful,[15,16,17,18] but the importance of the menisci is rarely stressed. The current study suggests that a combination of these injured structures may produce a change in muscle action, indicated by an altered angle of occurrence of peak torque. However, to be detected, it is necessary to use difference scores, averaged over two angular velocities and two motions.

Jackson[14] reviewed a series of patients with combined

anterior cruciate ligament and meniscal lesions who experienced episodes of "giving away." Sixty-two per cent of this group were subjectively improved following arthroscopic menisectomy and were subsequently able to function well without any surgical treatment. These patients had a high incidence of flap tears of the meniscus. Jackson concluded that removal of smaller meniscal fragments appeared to increase the joint stability, while the bulk of the meniscus was retained to function as a secondary restraint. Thirty-eight per cent of Jackson's group with combined lesions had required reconstruction of the anterior cruciate ligament to gain joint stability. These patients had more major tears of the meniscus in addition to anterior cruciate disruption, and had been injured at an earlier age.[14]

Levy et al[12] measured the effect of medial menisectomy on knee motion before and after section of the anterior cruciate ligament in cadaver knees. Their knee-testing apparatus allowed measurement of anterior-posterior force coupled with tibial rotation at multiple angles of knee flexion. Results of the study indicated that in knees in which the anterior cruciate ligament is intact, medial menisectomy did not influence anterior-posterior displacement of the knee in the early post-surgical period. However, in knees without a functioning anterior cruciate ligament, the meniscus could restrict anterior displacement of the tibia, and its excision might compromise the

intrinsic stability of the knee.

Jobe[20] stated that progressive degenerative changes after anterior cruciate ligament injury resulted in knee joint instability between twelve to eighteen months after injury. Time since injury in group I (knees with isolated anterior cruciate tears) in the present study, ranged from five to thirty-seven months. The time was less than eight months for five of the seven subjects. Time since injury in group II (knees with total anterior cruciate ligament tears, and partially removed menisci) ranged from six months to five years, and one subject was injured twelve years previous to the testing. This difference in time may have allowed for the progression toward instability described by Jobe, and may be a factor influencing the trend toward a change in the angle of occurrence of peak torque when averaged over two motions, flexion and extension, two selected angular velocities, and expressed as the difference between the injured and the uninjured legs. An increased time since injury might allow increased stretching of secondary soft tissue restraints to anterior tibial movement. It also allows for return to full physical activity which may involve alteration to accommodate for a knee injury. A corresponding change in muscle activity may be reflected in the tendency to change the angle of occurrence of the peak torque.

It is interesting to note that all subjects of groups I and II had the same clinical profile on examination: no

tests on examination of the knee were found to be positive, other than those for the injured anterior cruciate ligament, in all subjects in this study. Meniscus lesions were identified by arthroscopic examination. The results of the current study indicate that alteration in angle of occurrence of peak torque, and difference scores, may be useful diagnostic information in the future. However, because the significant differences observed in the present study were of a general nature, additional investigations are required to clarify this observation. Testing of greater numbers of subjects, particularly those who had been injured for the same mean length of time, would help to distinguish whether the cause for the significant difference of group II was a) time since injury, or b) a partially absent meniscus.

Peak Torque

Mean peak torque values at thirty degrees per second and one hundred and eighty degrees per second for uninjured legs of groups I and II and the stronger legs of group III were somewhat lower than those reported by Campbell and Glenn[20] for the uninvolved legs in their group. This finding is thought to be attributable to a higher mean age - thirty-one years in the present study as compared to twenty-seven years in Campbell and Glenn's study. The ratios of peak torque for knee flexor muscles to knee extensor muscles for the uninjured knee are in agreement

with those reported by Campbell and Glenn[20] and Steindler.[21] Steindler[21] reported a sixty-seven per cent ratio at a velocity of thirty degrees per second, and an eighty per cent ratio at one hundred and eighty degrees per second for normal legs. Ratios in the current study were sixty-five per cent and eighty-three per cent respectively for uninjured legs (see TABLE 12). Ratios of flexor to extensor muscle peak torque in the injured legs of groups I and II also conformed to the ratio for normal subjects, being sixty-eight per cent at thirty degrees per second, and eighty per cent at one hundred and eighty degrees per second angular velocities. This finding indicates that injured legs of subjects in groups I and II had developed normal strength ratios for flexor and extensor muscle strength over a period of time, without specific rehabilitation programs.

The results of the present study suggest a trend towards a change in the angle at which peak torque occurs during isokinetic movement in subjects with injured anterior cruciate ligaments and partially torn menisci. Significant differences in the angle of occurrence of peak torque were values averaged over both angular velocities (thirty and one hundred and eighty degrees per second) and both motions (flexion and extension). This difference does not indicate the magnitude, or direction of the change and must be interpreted as a general trend. More subjects need to be tested to determine the exact change in the angle of

TABLE 12

Flexion/Extension Peak Torque Ratios
(Expressed as Percentages)
in Three Investigations

Angular Velocity	Present Study Groups I, II		Steindler[15]	Campbell and Glenn[12]
	Injured legs	Uninjured legs		
30°/second	68%	65%	67%	68%
180°/second	83%	80%	80%	79%

occurrence of peak torque in isokinetic testing of injured legs. This information can be of value in making a differential diagnosis in patients with torn anterior cruciate ligaments, where present forms of clinical examination do not identify an additional injury to the meniscus. Knowing the typical angle of occurrence of peak torque during isokinetic movements of knees with injured anterior cruciate ligaments and partially torn menisci, also would provide a baseline of information about which rehabilitation goals can be determined.

A limitation of testing with the isokinetic dynamometer (Cybex® II) was the capability to test only for knee flexion and extension. If the knees of group I and group II subjects had progressive rotational instability, any change in muscle activity as reflected by a change in torque pattern, would be recorded in only flexion or extension movements.

This study was restricted by the availability of subjects who had an accurate diagnosis, confirmed on arthroscopic examination by one orthopedic surgeon. With the increasing popularity of arthroscopic procedures, subjects accurately diagnosed as having a torn anterior cruciate ligament, with or without a partially torn meniscus, will likely be more available in the future.

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CHAPTER 6

CONCLUSIONS

The purpose of the study was to determine if patterns of torque for knee flexion and extension differed between the injured legs and the uninjured legs of subjects in two groups: I) isolated anterior cruciate ligament injury, and II) anterior cruciate ligament injury with partially torn meniscus, and to determine if a similar difference existed between weaker and stronger legs in a third group: III) normal subjects. Analysis was based on data measured and calculated from the pen recordings of torque and angle curves produced during testing subjects on a Cybex® II isokinetic dynamometer.

Difference scores, values of the stronger or uninjured leg minus value of the weaker or injured leg, from groups I, II, and III were analyzed to determine if significant differences existed in the pattern of torque as determined by a) measurements at fifteen degree increments of movement, and b) angle of occurrence of peak torque. A four-way analysis of variance (three groups, with repeated measures over two types of motion, two angular velocities and five angles) was used to examine difference scores of patterns of torque as determined by measurements taken at fifteen degree

increments of movement. A three-way analysis of variance (three groups with repeated measures over two types of motion, and two angular velocities) was used to examine the difference scores for angle of occurrence of peak torque.

Further analysis on angle of occurrence of peak torque was completed using a Tukey multiple comparison test on the mean values of the raw scores measured from the pen recordings.

On the basis of the present study, the following conclusions were made:

1. No statistical support was found for the research hypothesis of alteration in torque patterns during isolated knee flexion and extension, when the primary restraint to anterior movement of the tibia on the femur was lost. Isokinetic torque-angle relationships observed during maximum voluntary isokinetic contraction of the hamstring and the quadriceps muscles, in legs with isolated injury to the anterior cruciate ligaments, (group I) were not significantly different than those produced by the normal contralateral leg, and a normal control group (group III).

2. The null hypothesis was rejected ($p<0.05$) in examining the pattern of torque as determined by angle of occurrence of peak torque. The torque-angle relationships of maximum voluntary isokinetic contraction of the knee muscles of subjects with torn anterior cruciate ligaments and a partial meniscal tear, with fragments removed (group II), indicate a change toward peak torque production at a

muscles of subjects with torn anterior cruciate ligaments and a partial meniscal tear, with fragments removed (group II), indicate a change toward peak torque production at a different angle, when averaged over angular velocity and type of motion and examined as difference scores. Subjects with isolated tears of the anterior cruciate ligament (group I) did not follow the same trend. This finding supports the research hypothesis of alteration in torque patterns during isokinetic knee flexion and extension, in response to a third degree sprain of the anterior cruciate ligament and partial tear of the meniscus. The finding may be attributed to the loss of both the primary and the secondary restraints to anterior movement of the tibia on the femur, and/or the increased time since injury (group I time since injury 15.4 months, group II time since injury 31.5 months).

Recommendations

The major recommendations that can be made from the current study are as follows:

1. More subjects be tested, repeating the same procedures, to confirm the data reported.
2. Testing of subjects injured for the same mean length of time in groups I and II, to help distinguish if the cause for the significant finding was time since injury, or partially absent meniscus.
3. Further investigation of muscle response to alteration in joint mechanics with isolated anterior cruciate injury be continued.
4. A similar study be carried out to investigate the angles of occurrence of peak torque of maximal isometric movements about knees with a history of partial loss of a meniscus.

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APPENDIX A

Informed Consent

Department of Physical Therapy
Faculty of Rehabilitation Medicine
University of Alberta
December, 1983

INFORMED CONSENT FOR INVESTIGATIVE STUDY

Isokinetic Torque Patterns
Following Anterior Cruciate Ligament Injury

Subject Consent (retained by investigator)

I _____ agree to participate
(Name - please print)

as a subject in the study entitled "Torque Patterns Following Anterior Cruciate Ligament Injury" to be conducted by Jane Proctor. The nature of this study has been explained to me, and I have been advised that I may withdraw from participation at any time. I understand that this is not a treatment.

Date: _____ _____
(Subject's signature)

_____
(Witness)

Department of Physical Therapy
Faculty of Rehabilitation medicine
University of Alberta
December, 1983

INFORMED CONSENT FORM FOR INVESTIGATIVE STUDY

Isokinetic Torque Pattern
Following Anterior Cruciate Ligament Injury

Outline of Procedures (Retained by Subject)

The purpose of the study is to examine a possible change in activity of the muscles of the knee following injury to the anterior cruciate ligament. The testing and preparation will require approximately one hour. You will be positioned at the Cybex® II machine and asked to complete two practice trials of three reciprocal repetitions each of extending and flexing the knee against the lever arm of the machine. For testing you will then be instructed to use maximal effort to repeat these movements for one trial of three repetitions at each of two different speeds of movement. Pen recordings will be made of the strength of each effort.

The information gained from investigation from investigation will be of benefit to therapists in planning exercise programs for patients with injured anterior cruciate ligaments, and potentially as an aid in diagnosing anterior cruciate ligament injuries. Risks are those of

normal exercise, the primary risk being muscular soreness or knee pain after exercise. Should you experience knee discomfort at any time during practice or testing, you may withdraw from participation as a subject in this investigation. Explanations for any questions you have regarding any aspect of the study will be given at your request. All records will be the property of the investigator and will be held in confidence. The report of the study will not include identification of the subjects.

APPENDIX B

Cybex® II Torque Channel Calibration Procedure

Cybex® II Torque Channel Calibration Procedure[1]

A. "Zero" or "null out" recorder to resting signal of Dynamometer.

1. Set DAMPING control at zero, CHART SPEED AT 5MM/SEC. and Speed Selector at 30°/SEC. (5RPM). Make sure there is no load on Dynamometer.

2. Set FT. LBS. SCALE on 180 and zero recorder stylus on baseline using AERO ADJ. knob for Torque Channel.

3. Switch FT. LBS. SCALE to 30.

4. If stylus deflects from baseline, adjust ZERO NULL potentiometer on side of recorder with calibration screwdriver to zero stylus on chart baseline.

5. Repeat steps 2 thru 4 until stylus deflects less than ½ minor division when sswitching back and forth between 180 and 30 ft-lb scales.

B. Calibrate Torque Range Scale.

1. Set Torque Channel to 180 foot-pound scale. Set DAMPING control at 3.

2. Set Speed Selector at 30°/SEC. (5RPM) and make sure there is no load on the Dynamometer. Adjust stylus to zero baseline using Torque Channel ZERO ADJ. knob.

3. Insert T-bar into long input adapter and set input arm at position marked "B."

4. Add 32.5 pounds of disc weights for calibration.

5. Set CHART SPEED at 5 MM/SEC.

---

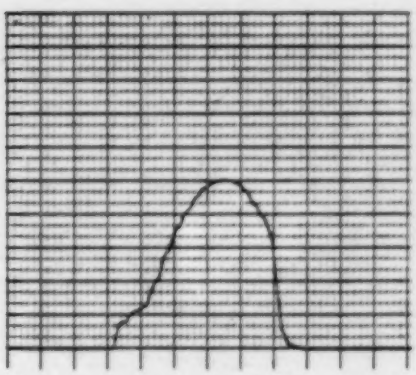
1. Cybex® II calibration instructions and record form, Cybex Division of Lumex Inc., 2100 Smithtown Ave., Ronkonhoma, N.Y. 11779.

6. Lift weighted T-bar to vertical position above Dynamometer. Pull or push weighted arm forward gently to engage Isokinetic resistance before letting go so that arm falls smoothly until it contacts the floor. Some practice is required to achieve a smooth weight swing with minimal oscillation on the floor where the weight contact is placed.

7. Check the torque reading on the chart recording. The peak value for each of the foot-pound scale settings should be as shown in FIGURE 15.

8. If the chart recording does not agree with the above value, adjust the potentiometer for the 180 foot-pound scale with the calibration screwdriver. Turning the potentiometer clockwise increases the torque reading, counterclockwise decreases it. The weight swing must be repeated each time an adjustment is made.

10. Remove calibration T-bar from long input adapter.



180 ft-lb scale – 5 major divisions above baseline (90 ft-lbs)

FIGURE 15: Peak value for the 180 foot-pound scale during calibration

APPENDIX C

Cronbach's Reliability Coefficient

Calculation of Cronbach's Reliability Coefficients for Measurement of Peak Torque and Angle of Peak Torque

Test-retest raw data

DAY:	1	2	3	4	5
PARAMETER:					
EXT 30°/sec.	80	82	81	80	80
FLEX 30°/sec.	77	77	77	77	77
EXT 180°/sec.	51	51	50	49	51
FLEX 180°/sec.	53	52	53	53	52

Peak Torque (in foot-pounds)

DAY:	1	2	3	4	5
PARAMETER:					
EXT 30°/sec.	36	36	36	36	36
FLEX 30°/sec.	55	55	55	55	55
EXT 180°/sec.	45	45	45	44	45
FLEX 180°/sec.	51	51	50	51	5

Angle of Peak Torque (in degrees)

Matrix of Pearson Product Correlation Coefficients

TEST DAYS	1	2	3	4	5
	r_{11}	r_{12}	r_{13}	r_{14}	r_{15}
	r_{21}	r_{22}	r_{23}	r_{24}	r_{25}
	r_{31}	r_{32}	r_{33}	r_{34}	r_{35}
	r_{41}	r_{42}	r_{43}	r_{44}	r_{45}
	r_{51}	r_{52}	r_{53}	r_{54}	r_{55}

Test-retest reliability is the comparison between measurement on test days

Cronbach's Alpha Reliability

$$a = \frac{nv}{nv-1} \times \frac{\text{(sum of covariances)}}{\text{(total sum of the variance-covariance matrix)}}$$

where: nv = number of variables
variance = diagonal values in the matrix
covariance = all other values in the matrix

Chronbach's Alpha Reliability for Measurement of Peak Torque

was r = 0.9996
and r = 0.9997 for angle of peak torque,

with 0.0004% of peak torque measurements,
and 0.0003% of angle of peak torque measurements attributable to error

APPENDIX D

Raw Data

GROUP I 30°/SEC (SPEED)

EXTENSION

INJURED							UNINJURED							
APT	PT	75°	60°	45°	30°	15°	75°	60°	45°	30°	15°	PT	APT	S
73°	127	117	106	68	34	6	114	132	97	56	24	134	65°	1
62°	154	142	153	103	64	10	127	148	103	60	18	150	63°	2
66°	112	92	82	58	38	20	118	96	74	46	20	102	64°	3
66°	111	74	107	85	52	26	74	108	94	52	20	122	60°	4
69°	94	39	102	82	56	-	100	123	100	48	-	120	75°	5
68°	159	144	132	117	75	18	158	122	111	66	18	159	75°	6
55°	90	42	84	80	46	18	116	116	82	42	10	134	67°	7

FLEXION

INJURED							UNINJURED							
APT	PT	75°	60°	45°	30°	15°	75°	60°	45°	30°	15°	PT	APT	S
46°	86	63	74	86	78	6	64	81	97	102	36	104	28°	1
30°	112	56	84	89	106	3	60	70	87	92	3	104	29°	2
26°	72	44	51	58	66	45	43	54	70	78	56	82	24°	3
27°	84	58	66	74	82	18	58	76	82	82	15	88	36°	4
36°	83	52	70	80	72	-	57	78	88	72	-	88	46°	5
28°	97	56	81	92	93	8	57	78	86	82	8	92	28°	6
41°	94	72	86	94	88	3	76	81	82	96	46	98	14°	7

Torque measured in foot-pounds at every fifteen degree position for injured and uninjured legs.

APT = angle of peak torque
PT = peak torque
S = subject

GROUP I 180°/SEC (SPEED)

EXTENSION

INJURED							UNINJURED							
APT	PT	75°	60°	45°	30°	15°	75°	60°	45°	30°	15°	PT	APT	S
45°	68	12	60	66	54	39	36	60	75	64	42	76	54°	1
56°	86	55	79	84	60	34	12	56	60	48	22	67	48°	2
44°	56	6	46	56	52	32	6	54	80	75	54	82	46°	3
48°	66	24	56	64	54	30	30	74	86	76	54	85	52°	4
50°	76	26	70	76	60	38	34	74	78	60	33	82	51°	5
44°	104	26	87	98	74	42	18	70	86	76	42	85	48°	6
60°	66	36	56	56	52	30	60	72	86	72	38	76	57°	7

FLEXION

INJURED							UNINJURED							
APT	PT	75°	60°	45°	30°	15°	75°	60°	45°	30°	15°	PT	APT	S
53°	55	52	54	49	36	22	36	60	75	64	42	74	58°	1
45°	52	28	46	46	36	6	46	59	64	63	18	65	42°	2
67°	52	52	46	38	15	2	63	74	72	50	22	76	70°	3
24°	45	32	38	35	38	38	44	56	62	64	52	65	30°	4
42°	68	58	65	66	52	24	52	67	70	64	51	70	51°	5
48°	76	66	74	72	62	16	18	64	86	76	42	72	54°	6
57°	67	42	56	46	32	9	58	72	74	63	18	85	39°	7

Torque measured in foot-pounds at every fifteen degree position for injured and uninjured legs.

APT = angle of peak torque
PT = peak torque
S = subject

GROUP II 30°/SEC (SPEED)

EXTENSION

INJURED							UNINJURED							
APT	PT	75°	60°	45°	30°	15°	75°	60°	45°	30°	15°	PT	APT	S
80°	142	142	106	66	22	-	104	102	63	28	3	126	79°	1
72°	110	106	100	70	30	0	124	125	70	30	2	147	72°	2
67°	86	74	50	21	10	0	80	106	92	46	4	126	66°	3
42°	206	198	196	148	94	8	196	216	156	108	20	224	67°	4
48°	214	212	188	152	96	18	208	184	112	68	18	216	67°	5
62°	114	76	98	78	34	4	110	98	90	46	-	130	70°	6
72°	98	93	80	78	46	16	42	48	65	64	6	106	77°	7
73°	81	75	64	51	26	-	87	94	34	28	-	100	67°	8
68°	164	154	140	105	60	-	189	158	112	62	22	189	78°	9
65°	172	164	162	112	76	45	124	148	114	72	16	164	77°	10

FLEXION

INJURED							UNINJURED							
APT	PT	75°	60°	45°	30°	15°	75°	60°	45°	30°	15°	PT	APT	S
40°	90	64	74	81	90	0	54	63	74	82	0	82	32°	1
48°	70	54	66	69	28	-	60	68	72	28	-	73	44°	2
27°	100	84	76	48	16	7	56	74	94	96	3	98	32°	3
32°	126	82	96	116	118	-	72	96	116	124	-	132	45°	4
22°	138	66	80	106	132	114	94	124	134	102	-	138	42°	5
32°	74	52	62	72	68	0	39	52	58	53	3	58	39°	6
32°	52	38	45	42	49	-	42	49	64	68	6	72	36°	7
37°	56	36	40	51	30	-	46	60	64	24	-	65	43°	8
39°	130	76	96	124	90	-	84	114	132	130	42	138	39°	9
34°	76	64	70	74	75	53	68	64	76	70	2	81	41°	10

Torque measured in foot-pounds at every fifteen degree position for injured and uninjured legs.

APT = angle of peak torque
PT = peak torque
S = subject

GROUP II 180°/SEC (SPEED)

EXTENSION

INJURED							UNINJURED							
APT	PT	75°	60°	45°	30°	15°	75°	60°	45°	30°	15°	PT	APT	S
51°	52	46	66	60	30	14	52	69	63	30	16	69	58°	1
51°	68	32	60	64	46	28	54	80	69	48	12	82	60°	2
63°	76	38	68	64	28	11	74	100	76	118	14	105	63°	3
49°	118	38	96	118	106	54	78	90	100	86	48	106	54°	4
54°	106	34	90	106	90	54	56	102	112	96	48	112	57°	5
44°	67	36	58	64	50	4	48	64	72	60	20	72	44°	6
54°	72	36	72	72	54	32	44	70	78	60	36	78	48°	7
48°	54	24	32	51	50	24	27	53	58	44	24	55	51°	8
48°	90	52	76	90	70	40	70	86	94	76	40	96	48°	9
45°	89	42	78	85	84	54	69	82	89	72	42	90	51°	10

FLEXION

INJURED							UNINJURED							
APT	PT	75°	60°	45°	30°	15°	75°	60°	45°	30°	15°	PT	APT	S
47°	52	36	44	52	36	9	19	36	52	38	15	52	41°	1
46°	48	34	48	42	30	8	52	51	46	32	12	54	60°	2
38°	60	38	56	60	51	6	60	71	84	64	3	86	33°	3
33°	94	38	80	84	84	48	68	78	84	69	16	88	42°	4
36°	92	72	82	85	78	54	90	94	90	75	18	94	58°	5
60°	50	44	50	46	36	6	34	38	36	34	4	41	68°	6
34°	35	24	30	34	34	34	42	46	51	42	12	52	40°	7
48°	52	36	50	52	45	18	38	46	44	36	18	45	39°	8
48°	88	72	86	82	60	46	54	62	70	70	22	70	52°	9
54°	58	54	57	56	46	12	60	64	60	50	12	67	54°	10

Torque measured in foot-pounds at every fifteen degree position for injured and uninjured legs.

APT = angle of peak torque
PT = peak torque
S = subject

GROUP III 30°/SEC (SPEED)

EXTENSION

RIGHT							LEFT							
APT	PT	15°	30°	45°	60°	75°	15°	30°	45°	60°	75°	PT	APT	S
72°	224	68	104	172	216	212	68	92	150	176	168	180	66°	1
68°	197	104	148	180	180	144	42	95	135	180	174	180	62°	2
61°	144	30	60	112	136	132	40	66	108	153	154	155	63°	3
69°	228	18	52	80	110	100	12	42	74	100	106	216	69°	4
54°	246	78	128	192	236	180	32	82	138	176	192	212	66°	5
81°	176	28	60	90	117	150	-	54	87	132	152	176	87°	6
55°	163	-	84	156	163	132	16	68	132	184	154	184	55°	7
67°	134	36	64	94	134	120	25	64	96	144	154	172	67°	8
69°	160	18	54	80	120	158	-	58	93	142	164	172	70°	9
81°	110	26	60	70	98	108	20	40	78	105	128	135	78°	10
60°	109	-	70	100	104	84	-	57	88	104	72	104	60°	11
75°	160	-	60	108	142	160	30	76	120	160	160	168	68°	12
65°	112	27	46	72	112	108	30	46	72	86	82	88	64°	13
60°	87	27	56	76	87	68	34	60	78	96	82	98	57°	14
69°	214	42	79	120	168	194	46	81	123	188	198	224	64°	15

FLEXION

RIGHT							LEFT							
APT	PT	15°	30°	45°	60°	75°	15°	30°	45°	60°	75°	PT	APT	S
28°	156	132	150	128	118	98	144	136	128	114	96	148	12°	1
33°	114	106	106	97	82	48	12	116	114	100	79	130	32°	2
18°	106	94	94	92	78	60	90	98	82	70	64	103	15°	3
30°	156	46	78	72	62	52	4	70	74	64	54	162	33°	4
30°	212	56	132	122	102	72	10	108	120	108	96	120	41°	5
24°	129	8	124	112	94	80	-	102	124	117	96	130	36°	6
45°	112	-	54	107	86	70	8	118	120	94	76	131	26°	7
20°	92	90	84	78	63	54	86	100	94	84	63	105	22°	8
37°	84	52	80	74	70	60	-	73	90	84	78	92	36°	9
30°	84	3	84	76	54	38	34	94	86	78	64	94	30°	10
30°	64	7	64	56	46	38	-	64	64	54	48	70	33°	11
33°	106	10	104	94	82	68	10	92	78	70	60	96	28°	12
28°	67	6	66	54	46	36	40	66	60	46	36	67	24°	13
18°	60	58	56	52	46	36	60	68	60	54	42	70	24°	14
29°	228	94	124	106	92	78	60	128	118	99	83	132	25°	15

Torque measured in foot-pounds at every fifteen degree position for right and left legs.

APT = angle of peak torque PT = peak torque S = subject

GROUP III 180°/SEC (SPEED)

EXTENSION

RIGHT							LEFT							
APT	PT	15°	30°	45°	60°	75°	15°	30°	45°	60°	75°	PT	APT	S
44°	142	88	110	142	128	96	54	88	114	125	110	124	54°	1
54°	119	72	106	116	119	108	60	98	110	106	78	112	45°	2
37°	76	60	78	83	78	66	64	80	82	72	52	82	42°	3
66°	122	36	78	116	124	80	54	94	110	128	116	127	57°	4
45°	121	72	102	120	104	60	60	84	114	114	80	120	54°	5
60°	136	54	96	132	135	117	36	72	108	126	108	128	67°	6
54°	76	36	66	76	76	60	28	66	84	74	30	84	48°	7
48°	81	64	80	84	78	66	46	70	80	64	30	79	45°	8
63°	96	54	78	92	95	88	46	82	92	94	76	94	55°	9
54°	80	36	56	76	74	62	36	54	66	69	58	70	54°	10
44°	62	48	59	61	54	38	22	40	53	57	47	57	58°	11
54°	94	36	78	94	88	70	36	66	90	92	78	66	38°	12
45°	70	90	114	106	96	80	38	58	63	58	50	63	42°	13
45°	45	24	38	45	40	30	24	36	46	46	36	47	54°	14
56°	122	60	94	115	122	114	36	78	108	124	114	124	51°	15

FLEXION

RIGHT							LEFT							
APT	PT	15°	30°	45°	60°	75°	15°	30°	45°	60°	75°	PT	APT	S
36°	107	82	84	100	94	84	82	90	100	96	82	100	42°	1
27°	92	6	92	60	72	64	66	54	74	70	58	84	18°	2
23°	72	56	72	68	64	58	62	71	57	40	30	71	30°	3
49°	104	18	82	90	96	88	4	104	108	90	78	108	48°	4
45°	70	30	52	70	64	60	22	42	69	64	58	69	36°	5
44°	108	5	66	102	102	90	60	90	96	104	100	104	66°	6
54°	73	5	64	72	74	60	4	42	54	72	62	72	54°	7
32°	50	6	34	48	48	36	40	53	52	48	38	52	27°	8
39°	62	22	50	54	58	54	58	62	66	66	49	66	24°	9
20°	60	36	52	58	48	22	48	48	60	55	46	63	33°	10
39°	48	42	47	48	40	34	18	36	45	42	38	44	43°	11
36°	66	36	54	64	63	56	18	60	66	63	58	94	54°	12
46°	58	43	52	58	56	48	38	50	54	52	44	56	34°	13
21°	38	24	30	35	34	32	38	39	36	34	30	39	24°	14
53°	78	6	58	69	77	73	6	60	66	74	68	78	48°	15

Torque measured in foot-pounds at every fifteen degree position for right and left legs.

APT = angle of peak torque PT = peak torque S = subject

APPENDIX E

Clarification of Four-Way ANOVA

Clarification of Four-Way ANOVA

Main Effects:

(Repeated Measures)

A groups (I, II, III)
B degree (30°, 45°, 60°, 75°)
C type (flexion, extension)
D speed or angular velocity (30°/sec., 180°/sec.)

Factors:

3 x 4 x 2 x 2 = 48 cells

Interaction:

1st Order	2nd Order	3rd Order
AB	ABC	ABCD
AC	ACD*	residual ACD**
AD	ABD*	
BC	BCD	
BD*		
CD		

* indicates significance at the $p<0.05$ level
** the residual factor is necessary to compensate for unequal cell size, due to unequal groups